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VEHICULAR INTERCOMMUNICATIONS SYSTEMS.(U)

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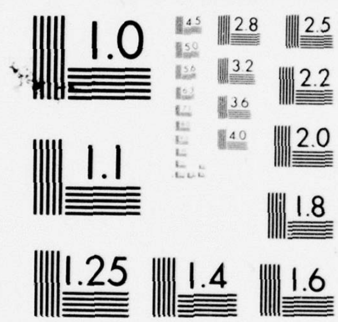
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CORADCOM -77-0189-F

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VEHICULAR INTERCOMMUNICATIONS SYSTEM

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January 1979

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is a final report for the design study for a Vehicular Intercommunications System (VIS) primarily for tracked vehicles. The purpose of this study was to investigate wireline and wireless techniques for system signaling and control for application to a tracked vehicle intercom system and then select the best techniques and establish a baseline intercom system. This report provides the criteria used for technique selection and an explanation of the baseline system. The baseline system utilized a microprocessor control system, a time division → next page

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20. ABSTRACT (Cont)

multiplex signaling system and an infrared or UHF FM wireless technique. The final wireless technique selected is dependent on whether or not external access to vehicle radio or intercom is required.

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FOREWORD

This Final Report on the Vehicular Intercommunications System Study, Contract DAAB07-77-C-0189, is submitted 18 December 1978 for the period 29 September 1977 through 24 September 1978 by ITT Aerospace/Optical Division, 3700 East Pontiac Street, Fort Wayne, Indiana 46803. Technical Monitor is Mr. Glenn Williman, DRDCO-COM-RN-3. ITT-A/OD Report Number is 311A002.

1 INTRODUCTION

The Vehicular Intercommunications System (VIS) study was implemented to provide a baseline vehicular intercom primarily for tracked vehicles which would be the replacement for the presently used AN/VIC-1 intercom system. The new VIS was to incorporate today's technology into a baseline system which would provide an improvement in audio quality, operational capability over the AN/VIC-1 intercom and would also interface with the SINCGARS-V VHF-FM radio currently under development. Part of the operational capability improvement was to investigate applicability of a "wireless" intercom system. How a wireless system would be implemented and what technique would operate best in the wireless intercom transmission medium were investigated. The primary design areas addressed in the investigation to form the baseline system were:

- Control techniques
- Signaling techniques
- Techniques/or wireless intercom
- Voice actuated switch (VOX) techniques

To provide a system which would best fulfill the intercom requirements, interviews with users at Fort Knox and at CORADCOM were held to provide a good base from which the intercom was configured. The major considerations used in developing the system configuration were:

- Operational simplicity
- Ease of installation as a new system
- Retrofit capability into current field equipment
- Assurance of correct system operation (BITE)

System configuration, mechanical configuration and piece part selection for the VIS were monitored by the Logistics Support Analysis (LSA) group to assure that the system was easy to maintain, logistically readily supportable and would have a low life cycle cost.

The culmination of the study, resulted in an intercom system which when compared to the current AN/VIC-1 has fewer components, has expanded operational capability, and is capable of being packaged in the same size as the present intercom components.

The VIS is configured as two subsystems. The first is the cabled system which meets all of the requirements of the procuring specification DS-AF-0246A(A) and requires cabling between the corresponding crew station. The second subsystem adds crewmember wireless capability to the first subsystem.

As a result of the ITT-A/OD study a microprocessor was implemented into the baseline system as the central controller. A TDM multiplex signaling system will be used along with the implementation of the Continuously Variable Slope Delta modulator (CVSD) devices for the analog-to-digital and digital-to-analog conversion of the audio signal which is multiplexed with the control signals for routing between the command station and the crew station. Two wireless techniques are recommended, depending on actual wireless requirement. For internal use in the tracked vehicle an infrared (IR) system is best suited and if both internal and external use is required, a UHF FM system will best fulfill the wireless requirements.

This report highlights the study effort and defines the criteria and data used in selecting techniques which form the baseline VIS.

2 INTERCOM SYSTEM REQUIREMENTS AND SYSTEM DEFINITION

The initial effort in the VIS study was to establish the requirements of the intercom system. Sources for this information were specification DS-AF-0246A(A) CORADCOM, and Fort Knox. The new intercom will incorporate technology improvements to provide the following:

Electrical Requirements -

- Improved audio quality
- Improved operation capability
- Compatible with AN/VRC-12 and SINCGARS-V radios
- Provide remote control for SINCGARS-V
- Reduce cabling between crew and command stations
- Utilization of fewer slip rings in turret type vehicles
- Have the capability to operate as a secured system with COMSEC equipped radios
- Provide hands free intercom operation

Mechanical Requirements

- Ruggedize failure points in the AN/VIC-1 (binding posts, volume control, external microphone cable)
- Ease of installation in either the M-60 or XM-1 tanks

These major requirements were used to guide the development of the intercom system and also to measure the applicability of control, signaling and wireless techniques examined for use in the intercom system.

Intercom Configuration

The VIS is required by the specification to provide intercom and radio access to eight users. One of these users will be defined as the external station whose intercom and radio access will be controlled by the commander. The intercom system was developed to provide the specified functional requirements with the fewest number of components possible. Of the several configurations considered, the intercom shown in Figure 2-1 best fulfilled the requirements. This system requires three components for a cabled intercom system.

- Commander's control station
- Internal crew station
- External crew station

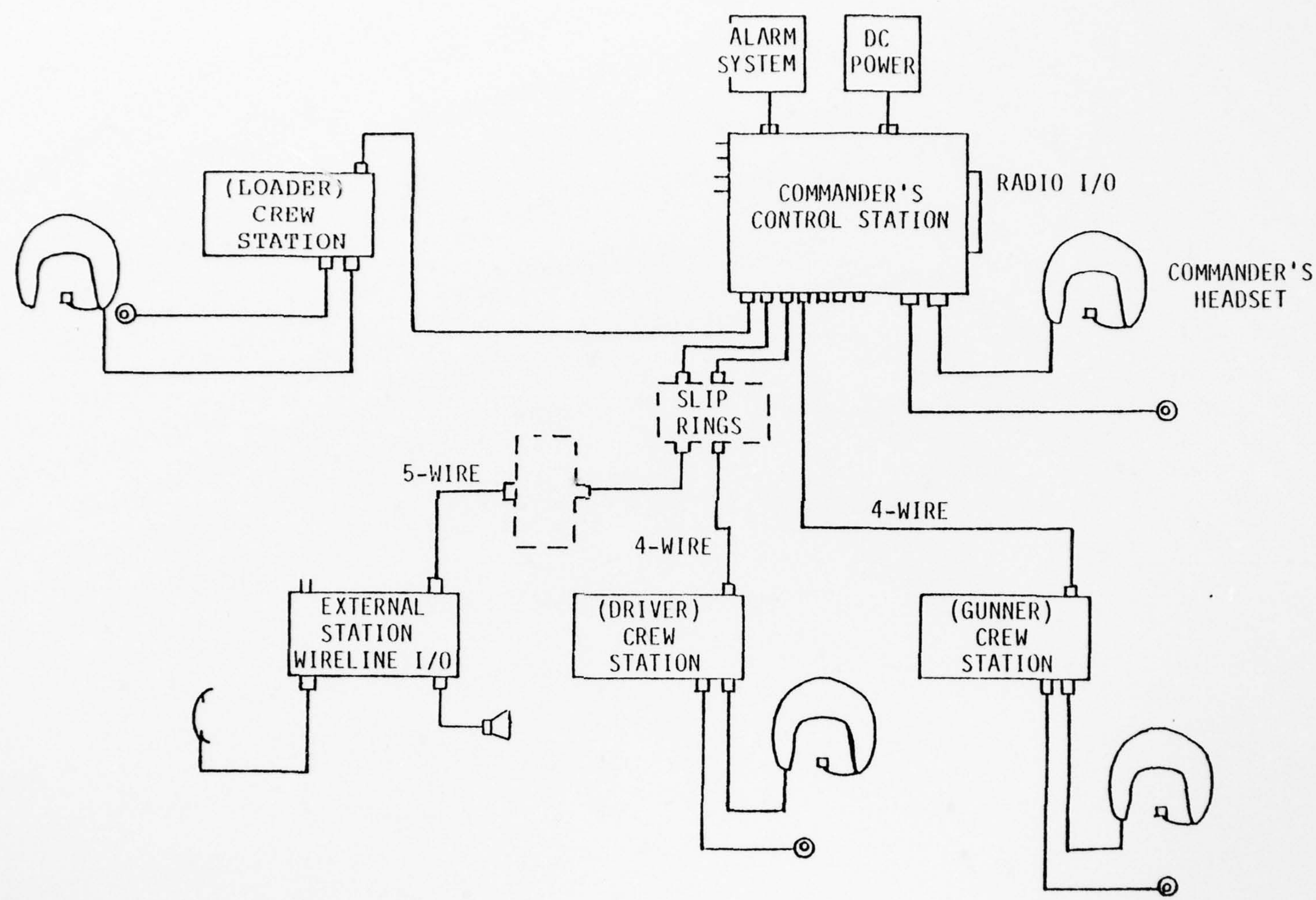


Figure 2-1. Cabled Intercom Subsystem with Auxiliary Commander's Station to Equip M60 or XM-1 Tank

The external crew station has a very specific use and is controlled at the commander's station for its operation. WIthout this special need, the intercom system would contain only two components.

The commander's station can also be utilized as an auxiliary commander's station with no modification. The auxiliary command station can perform the same radio control functions as the command station, and both stations will be updated when a radio control change is made.

When the wireless requirement is considered three additional components are added to the system.

- Internal wireless crew station
- Wireless crew set
- External wireless crew station

The wireless components when added to the intercom system do not require change to the cabled subsystem and therefore can be added to or taken out of the system at will. The VIS with wireless components is shown in Figure 2-2.

The intercom system must provide the following capabilities:

Commander's Control Station

a. Radio Equipment Control

1 Power - capability to turn power ON/OFF to the three SINCGARS-V radios as a group and the AN/PRC-77 radios as a group.

2 Power level control of transmitter (SINCGARS-V only) - capability to select any one of six power levels for each radio.

3 Frequency preset select (SINCGARS-V only) - capability to select any one of six presets for each radio.

4 ECCM control (SINCGARS-V only) - capability to set each radio individually to ECCM or Non-ECCM mode.

5 COMSEC control - capability to set each COMSEC unit individually to either cipher text or plain text. COMSEC units controlled are VINSON and VANDAL.

6 Retransmit control - capability to place radios two and three in retransmit mode allowing crew members to monitor and commander to transmit over and monitor retransmit radios.

7 Radio access control - provide capability to disable crew from transmitting on the radio and provide the capability for the commander to hear the radios only (i.e., crew silence).

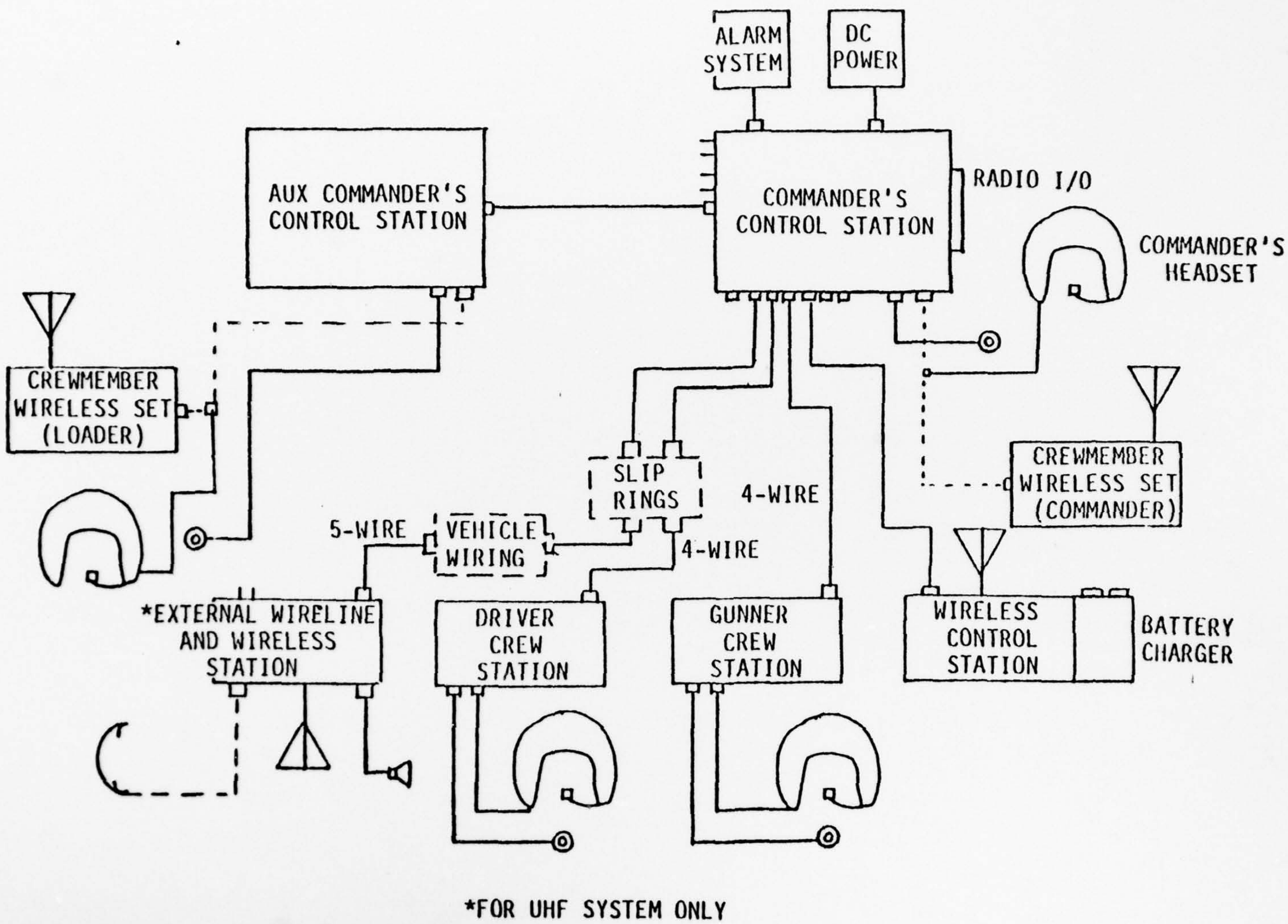


Figure 2-2. **Wireless Subsystem to Equip M-60 or XM-1 Tank**

b. Radio Equipment Audio Controls

1 Received audio control - capability to select any one of the following five:

a Intercom only
b Intercom plus radio one
c Intercom plus radio two
d Intercom plus radio three
e Intercom plus all three radios

2 Trans audio control - capability to select any one of the following four:

a Intercom only
b Intercom or radio one
c Intercom or radio two
d Intercom or radio three

3 Accent control - capability to select any one of the following three:

a Radio louder than intercom
b Intercom louder than radio
c Equal audio levels

c. External Station Control

1 Disable - external station cannot transmit or receive over the intercom or radios.

2 Request for access to intercom system generated from external station to be shown on front panel by a flashing light.

3 External station enabled to use intercom system indicated by a light being on.

4 External station call - flashes light at external station.

5 Receive audio control - be able to select any one of the following five:

a Intercom only
b Intercom plus radio one
c Intercom plus radio two
d Intercom plus radio three
e Intercom plus all three radios

6 Transmit audio control - be able to select any one of the following four:

a Intercom only
b Intercom or radio one
c Intercom or radio two
d Intercom or radio three

d. Power Control - capability to turn on intercom power only or intercom plus radios.

Front Panel Control Functions Descriptions.

To provide all of this control capability on a front panel no larger the AM-1780 required several iterations. Of the many considerations used in developing the commander's control panel the major ones are:

- Operation of intercom with winter gear.
- Operation of intercom in low ambient light
- User skills and attitudes
- Minimization of erroneous operations

In development of the commander's control panel, the combining of similar functions and also the placement of associated controls in close proximity to each other resulted in the panel shown in Figure 2-3.

The functions of the front panel are described below:

a. POWER CONTROL

1 OFF - No power to intercom or radios
2 NORM - Power Supplied to intercom and all radios
3 INT ONLY - Power Supplied to intercom only, no power to radios

b. RADIO STATUS - Preset, RF power, ECCM and COMSEC displays show the status of the radio specified by the radio select switch. When in ECCM mode, the light is ON. Likewise when transmitting CT, the light is ON. The dimmer switch controls the intensity of the displays.

c. STATUS CONTROL

1 RAD SEL - specifies the radio to be displayed and specifies the radio upon which the preset, RF power, ECCM, and COMSEC switches operate upon. These switches are bidirectional, spring-loaded so as to return to the center up position. The center up position is inactive.

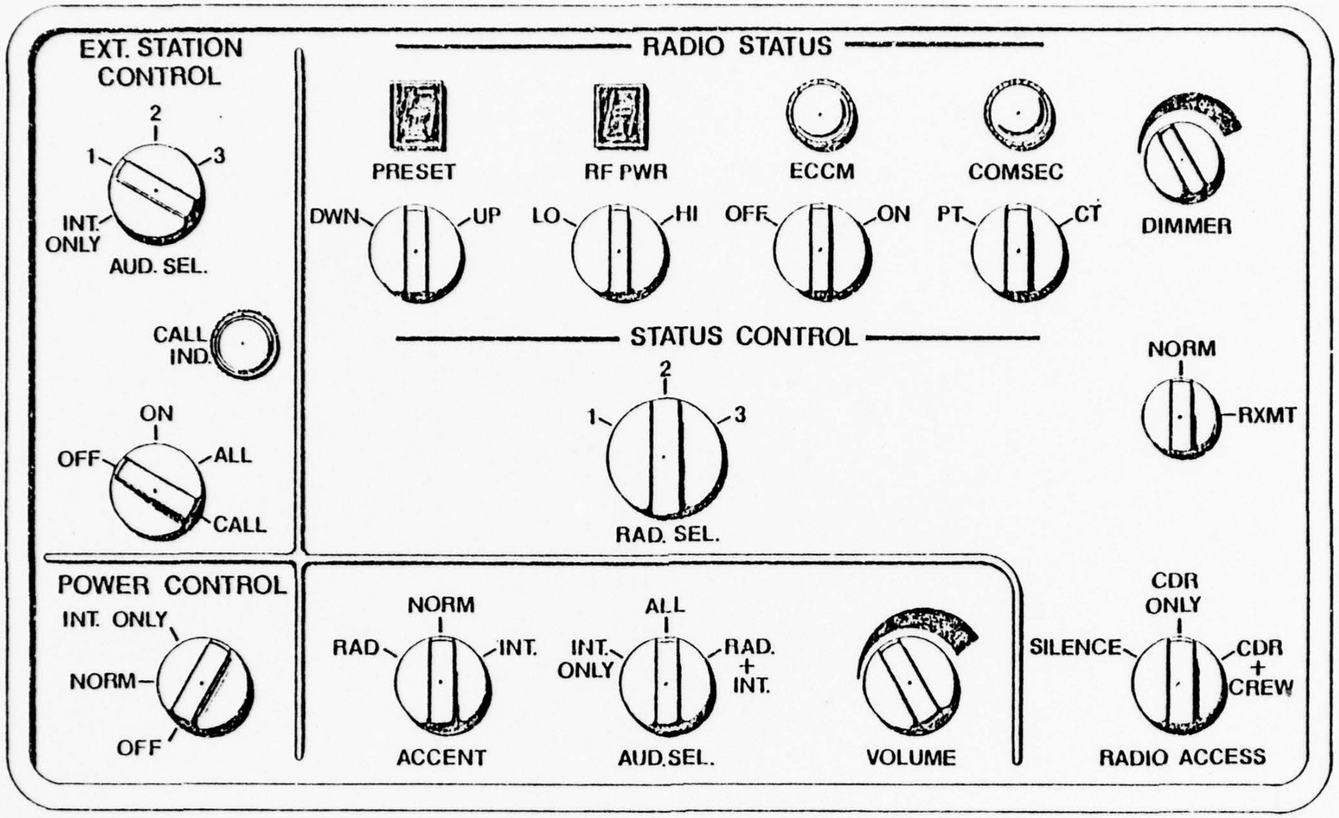


Figure 2-3. Commander's Control Station with Combined Radio and Intercom Control

2 PRESET - There are six possible presets. When incrementing the preset it is possible to loop around (i.e., upon reaching 6, one more increment will cause preset to go to 1.) When decrementing it is also possible to loop around.

a UP - A momentary turn to this position increments the preset or the radio specified by the radio select switch.

b DOWN - A momemtary turn to this position decrements the preset of the radio specified by the radio select switch.

3 RF PWR - There are six possible power levels. The RF power display does not loop around. Upon reaching the highest power level the counter does not turn over to the lowest. The commander must instead decrement six times.

a HI - A momentary turn to this position increases the RF power of the radio specified by the radio select switch by one level.

b. LO - A momentary turn to this position decreases the RF power of the radio specified by the radio select switch by one level.

4 ECCM

a OFF - A momentary turn to this position places the the radio specified by the radio select switch out of ECCM mode. Light goes OFF.

b ON - A momentary turn to this position places the radio specified by the radio select switch into ECCM mode. The light turns ON.

5 COMSEC

a PT - A momentary turn to this position places the radio specified by the radio select switch into plain text mode. Light goes OFF.

b CT - A momentary turn to this position places the radio specified by the radio select switch into cipher text mode. The light turns ON.

d. RETRANSMIT

1 NORM - Radio two and three may be used by commander and crewmembers to transmit on. Only in this position can the status of radios two and three be changed.

2 RXMT - Radios two and three are connected together through the intercom for retransmit on presets and RF power levels selected using status control. Status of radios two and three cannot be modified while in retransmit mode. Crewmembers cannot transmit on radios two and three but may monitor these radios.

e. RADIO ACCESS

1 CDR + CREW - Commander and crewmembers may transmit and monitor radios as well as use intercom.

2 CDR ONLY - The crewmember's stations are disabled from transmitting on the radios. The crew still can listen to the radios and use the intercom. The commander can transmit and receive on the radios as well as use the intercom.

3 SILENCE - The crew member's stations are entirely disabled from transmitting on the radios or intercom. They can only listen. The commander can still transmit and receive over the radio as well as transmit over the intercom.

f. ACCENT

1 RAD - Accent the radio so as to be louder than the intercom.

2 NORM - Radio and intercom equally loud.

3 INT - Accent the intercom so as to be louder than the radio

g. AUD SEL

1 INT ONLY - Disables the commander from receiving or transmitting on the radios.

2 ALL - The commander receives all three radios and transmits only on the radio specified by the radio select switch. The commander will receive and may transmit on the intercom also.

3 RAD + INT - The commander receives and transmits only on the radio specified by the radio select switch. The commander will receive and may transmit on the intercom also.

h. VOLUME - Adjusts the loudness of the commander's headset.

i. EXT STATION CONTROL

1 CALL IND - Flashes when an external user presses the push-to-talk button provided the external station is turned OFF. Light is ON when external station is enabled.

2 OFF - External station is disabled from listening or talking to radios or intercom.

3 ON - The external station receives and transmits only on the radio specified by the aduio select switch. The external station will receive and may transmit on the intercom also.

3 ALL - The external station receives all three radios and transmits only on the radio specified by the audio select switch. The external station will receive and may transmit on the intercom also.

5 AUD SEL - Specifies which radio to transmit on. Also provides the intercom only function which disables the station from receiving or transmitting on the radios.

The use of seven segment displays allows for information update when a commander's station and auxiliary station are operating together. When a change of RF power or frequency preset is made either at the commander's or the auxiliary commander's station, this information will be updated at both locations. When the changed radio is selected, this new preset and or power setting will be displayed.

Crew Station

A crew station will have the capability to control:

a. Received Audio Control - capability to select any and one of the following five:

1 Intercom only
2 Intercom plus radio one
3 Intercom plus radio two
4 Intercom plus radio three
5 Intercom plus all three radios

b. Transmit Audio Control - capability to select any one of the following four:

1 Intercom only
2 Intercom plus radio one
3 Intercom plus radio two
4 Intercom plus radio three

c. Audio I/O

1 CVC Helmet I/O
2 Remote PTT I/O

a Intercom PTT
b Intercom plus Radio PTT

The control requirements for the crew station are much simpler than those at the commander's control station. The crew station front panel is shown in Figure 2-4. The switching for selection of operating modes at the crew station is done in the same manner as the commander's station, with a radio select and audio select control. Operation is therefore the same as that of the commander control station.

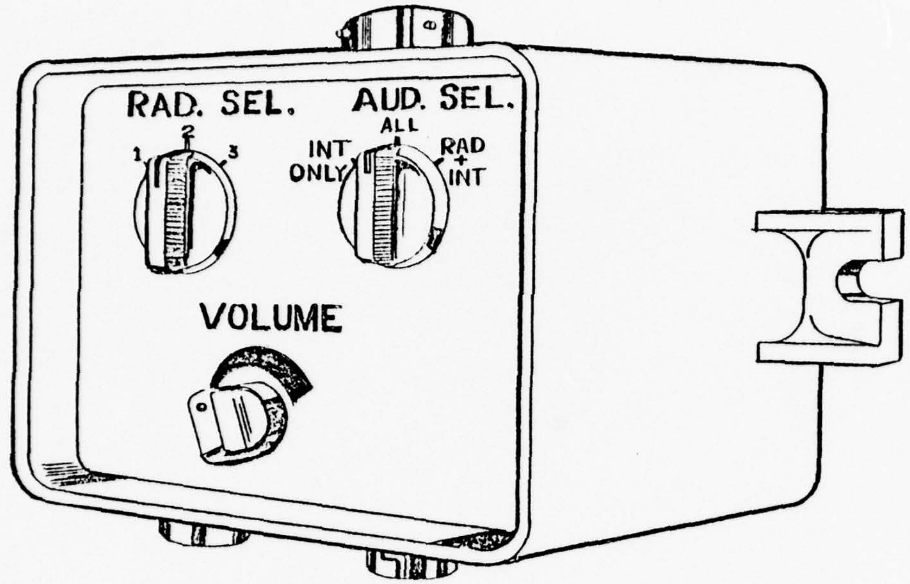


Figure 2-4. Crew Station Control Box

External Crew Station

The external crew station must acquire access to the intercom via the commander's control station. The external user flashes the commander's station by pressing the PTT switch of the hand set supplied at the external crew station. The commander has the capability of providing the same operational modes to the external crew station, as those available to the internal stations.

Wireless Internal Crew Station

The wireless internal crew station provides the same radio and intercom access as the internal crew station. The operation mode select is the same. Added to the wireless station is an on/off control which enables the operator to disable the wireless station. The wireless crew station shown in Figure 2-5 also provides a battery charging capability for two battery packs thus enabling two wireless users constant wireless operation per wireless crew station. This will provide wireless intercom capability to the commander and the loader, the two most mobile crew members.

Signal Flow of the ITT-A/OD VIS

The VIS utilizes the commander's station as the central distribution point. All audio signals from the crew stations and the radio's are routed to the commander's control station. These signals are then routed to the proper destination as determined by the programming of the radio select and audio select switches of the commander's control station and the crew stations. The operation mode request is routed to the commander's control station and refreshed periodically.

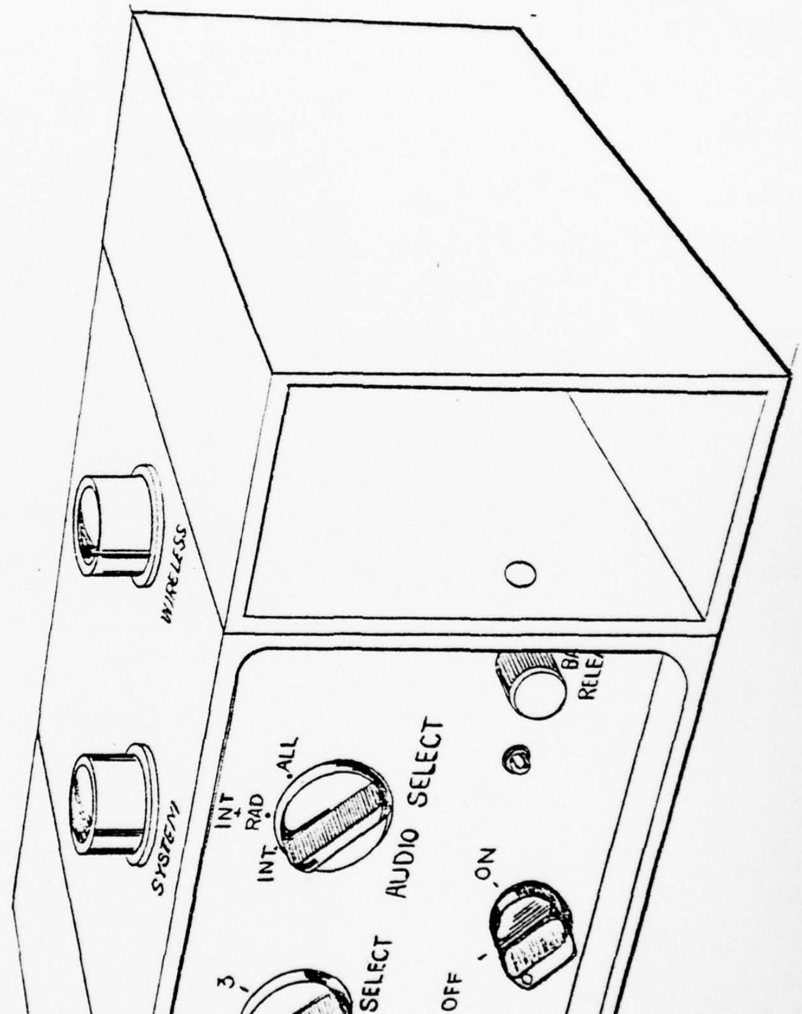


Figure 2-5. Internal Wireless Crew Station

3 EVALUATION AND DEVELOPMENT OF TECHNICAL APPROACHES

Using the system requirements as a guide, areas of the intercom system were defined for which there were multiple technologies which could meet these requirements. These areas are:

- Signal distribution
- Signaling techniques
- Intercom control
- Wireless propagation

Under each area, alternate approaches were defined which would fulfill the required functions. These approaches were then analyzed to determine which would best fill the requirement. Criteria for technique selection was established to provide guidelines for selection of the best techniques. Performance criteria were also established. These criteria are operational suitability, reliability, maintainability, EMC/TEMPEST, environmental suitability, available technology, and life cycle costs. Each of these criteria are described briefly in the following paragraphs.

Operational Suitability

The equipment must be easy to operate and the human engineering concepts must allow for easy access to all controls to allow for fast change of control settings under battle stress conditions. The system design should not require multiple operations to accomplish simple functions. The equipment should offer flexibility to change and provisions to add control of additional equipment if the system should require expansion. Training in the use of the system should be simple and not require any unusual mental dexterity to become proficient in the use of the hardware.

Reliability, Availability, Maintainability

The equipment must be reliable and easy to maintain using components that are sufficiently rugged to withstand the constant field use of track type vehicles. The equipment must be designed so that a failure in one portion (substation) will not disable the entire system. The equipment must have an electrical design which allows for straightforward logical troubleshooting techniques and a mechanical design which allows access to components for troubleshooting functions should a fault occur. There should be no alignment of LRU's under field conditions, no levels to be critically adjusted depending on environment or age of equipment, only connectors and cables or proven reliability, and only components with large design safety margins.

EMC/TEMPEST

Once a system intercom approach has been postulated, it must be evaluated against other systems in terms of EMC, EMI, and TEMPEST performance. Certain items of EMC and TEMPEST protection are standard for all system approaches. These include:

- Wireline shielding,
- Power line filtering, and
- Out-wrap shielding of modules and assemblies.

There are areas of EMC/TEMPEST design where one system approach because of its unique design properties will exhibit superior performance over other approaches.

Just as the intercom system must not interfere with other systems, it must also be designed to reduce its own susceptibility to electromagnetic interference (EMI). In contrast to EMC performance, a digital TDM signal distribution approach exhibits superior EMI rejection compared to discrete analog signal distribution approaches.

In the area of TEMPEST evaluation, each system approach must be designed to suppress correlated RED signal emanations. The cost of TEMPEST protection can often be minimized by selection of a particular design approach.

Environmental Suitability

The environmental suitability of the proposed technologies which may be employed in the design of a new intercom system is an overriding consideration. Because all proposed wireless systems must be battery operated, the performance of batteries at low temperture is a serious concern. Acoustical noise impacts the design of a wireless system in which high frequency sound is used as a transmission medium while stray light sources and sunlight constrain the use of infrared energy in a wireless system. RF noise and RF energy radiated by on-board electrical equipment, static discharges, and radio equipment restrict the choice of frequencies for an RF wireless link. In addition, there are health hazards associated with microwave, ultrasonic and infrared energy.

Available Technology

All the technology required to design a new intercom system utilizing any of the techniques discussed in the proposal is available today with the possible exception of a rechargeable battery which will accept a charge at low temperatures. Some of the components used in fiber optics are relatively expensive today. In a 1980's time frame, however, cost is not expected to be a problem.

Life Cycle Cost

Research and development and production costs were estimated for the more promising systems and provided to the Integrated Logistic Support team for use as inputs to the Logistic Support Analysis Model (LSAM) which includes reliability, maintainability, and descriptions of all parts. This permited the LSAM to provide total system life cycle costs, in addition to logistic life cycle cost, operational availability, etc., for each system. Results of the LSAM system life cycle cost analysis were weighed and utilized as a most critical criterion in final system selection.

Technology Analysis

Distribution Methods

The two distribution systems that have been considered are Bus distribution and Star distribution. In a Bus distribution system there is one main bus carrying information for all of the substations. This requires multiplexing of information for use by the substations. In a Star distribution system, each substation has its own bus. The Bus distribution method has the advantage of reducing interconnecting wires to a minimum but is has the disadvantage that a single bus failure due to combat damage or ordinary electrical failure can disable the whole intercom system. The reliablity of a bus system can be increased by operating parallel busses. A Star distribution system increases overall intercom reliablity, since combat damage to one station does not affect the entire system. Individual signal distribution requires an increased number of cables and connectors. This can be reduced by multiplexing control information onto the voice channel either in terms of tones or a Time Division Multiplexing (TDM). A Star distribution system lowers the operating frequency of the interconnect lines. This is particularly important due to the anticipated problems of noise susceptibility when passing through the tank slip rings. In summary of distribution technques, the Star system were chosen over the Bus system because of increased reliability and lower operating frequency.

Signaling Techniques

The use of multiplexing techniques reduces considerably the number of interconnecting wires between the commander's control station and the user's substation. This reduces the cost of connectors and cables. The reduction of cable-wire count is also very important for tank installations where the number of turret slip rings is limited. The three multiplexing techniques considered were Time Division Multiplexing (TDM), Frequency Division Multiplexing (FDM) and Space Division Multiplexing. In a TDM system, voice signals are sampled and encoded in an asynchronous serial bit stream. Voice signals are then assigned specific time slots for transmission on a single wire to the user. Command information is easily interleaved with the digital voice for transmission on the same line. In a FDM system, command information must be encoded as multifrequency tones for transmission on individual voice channels. Filters must be designed to decode this information. In Space Division Multiplexing, separate wire lines are used to route the required voice and control information to each user.

The advantage of TDM over FDM is the suppression of the high background noise characteristic of current analog systems since information is carried in the absolute levels of the data bit (additive noise is removed when the decision is made between logic "0" and "1"). A TDM system uses all digital signal processing which requires no special alignment or tuning. Digital circuit designs exhibit increased reliability over analog circuits and can be easily packaged as custom LSI networks to decrease system size and cost. A TDM system lends itself very well to the use of fiber optics.

The advantage of Space Division Multiplexing is that it requires very simple electrical circuits to provide for the distribution of the various signals. Its main disadvantage is that a large number of wirelines is required to transmit the required information and this results in bulky cables and large expensive connectors. A compromise can often be made in designing wireline communication networks by combining the salient attributes of TDM and Space Division Multiplexing. In the intercom system, separate wirelines could be employed by voice and control information. Control bits would be multiplexed on a separate unbalanced wireline at a very low bit rate. High speed digital voice signals would be multiplexed on separate balanced wirelines. The advantages and disadvantages of the above multiplexing techniques are summarized in Table 3-I.

Table 3-I. Multiplexing Technique Trade-Off

Multiplexing Technique

Criteria	FDM	TDM	Space Division Multiplexing	Hybrid TDM Plus Space Division
Noise Immunity	1.Analog FDM Signal Distribution techniques are susceptible additive noise.	1.Digital TDM signal distribution techniques provide a measure of additive noise rejection.	1.If separate wireline distribution is used digital voice encoding should be used in preference to analog voice to provide noise rejection.	1.Digital voice encoding provides noise rejection.
Circuit Complexity	1.Relatively complex frequency tuning network required to provide channel selection. Analog tone generator/ detectors required to transmit control information.	2.Relatively simple digital timing networks required to provide channel selection. Digital CVSD encoders available as off-the-shelf LSI circuits.	2.No channel selection circuitry required. Simple switching provides selection of appropriate channel.	2.Channel selection cuitry minmized. Off-the-shelf UART's can be used to process serial TDM control data.
Wiring	3.Multiple wireline cables reduced. Connector size reduced.	3.Multiple wireline cables reduced. Connector size reduced.	3.Several wirelines required and large cable connectors.	3.Relatively few wirelines and smaller connectors than space division approach.

30

On the basis of the results in Table 3-I, FDM multiplexing was not considered viable since it provides no measure of noise rejection so critical to the intercom system and also the high degree of circuit complexity is costly. The Space Division Multiplexing approach was also rejected since it requires a large number of wirelines which result in bulky cables and expensive large connectors. The large connectors are also not practical, given the fact that seven crew members stations must be connected and a small intercom form factor is required (i.e., panel space for connectors is limited). This left TDM and a hybrid TDM approach as the most viable condidates.

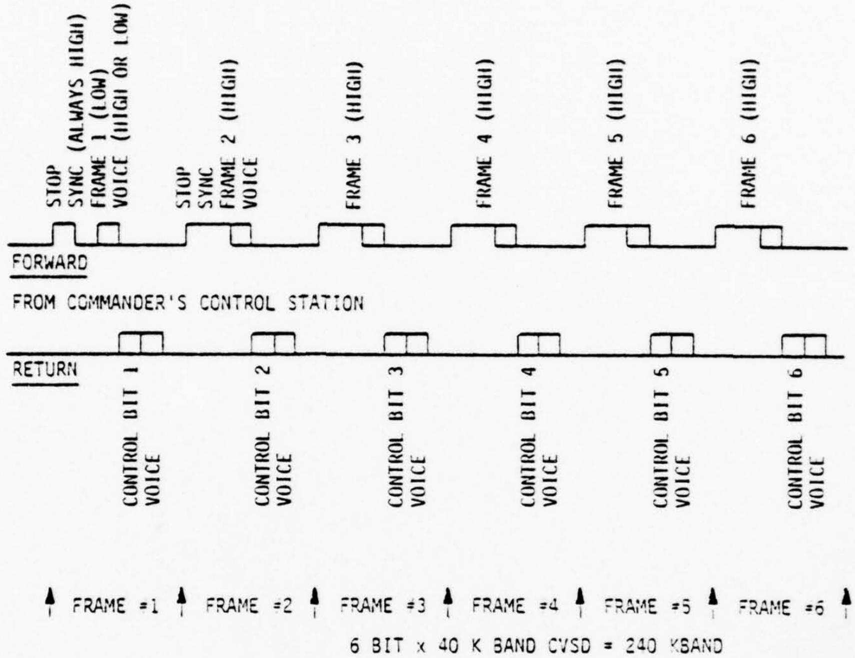
For further analysis of the two remaining singnaling techniques, intercom systems were developed around each one.

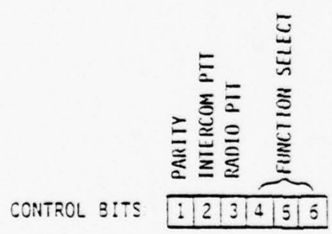
TDM System

In designing a TDM system, a major emphasis should be placed on specifying a format for transmission of digital information between the commander's control station and the user's substation. Formatting affects the operating frequency of the transmission line and consequently the areas of: compromising emanation, noise susceptibility, generation of noise affecting other vehicular systems and power consumption. Other areas affected by formatting include error rates and control bit synchronization. In summary, the three objectives are:

- Lowest possible bit rate,
- Low error rate,
- Ability to re-acquire synchronization without a noticeable degradation of system performance.

Since a Star distribution technique is being used in transmission of data it is possible to route the digital information to and from all the crew stations simultaneously. This results in a slight increase in hardware at the commander's control station but is offset by a decrease in substation hardware and simplicity in designing low frequency drivers and digital circuitry. Further decrease of system operating frequency can be accomplished by simplifications of synchronization bits allowed by decrease in voice bits transmitted. Figure 3-1 illustrates this. The format is similar to that of a universal asynchronous receiver transmitter. Synchronization is accomplished by detecting the positive transition of the synchronous bit. Data is detected by sampling the line at fixed intervals in relation to the synchronization bit. A stop bit is added to verify proper timing and framing. The stop bit guarantees a transition when the synchronization bit is transmitted.





FUNCTION SELECT:

BIT 4	BIT 5	BIT 6	SWITCH POSITION	XMIT	RCV
0	0	0	INTERCOM ONLY		
0	0	1	INTERCOM + RADIO	1	1
0	1	0	INTERCOM + RADIO	2	2
0	1	1	INTERCOM + RADIO	3	3
1	0	1	INTERCOM + RADIO	1	1,2,3
1	1	0	INTERCOM + RADIO	2	1,2,3
1	1	1	INTERCOM + RADIO	3	1,2,3

Figure 3-1. TDM Format

Figure 3-2 gives the Voice Signal Interconnect Diagram for TDM Signal Distribution. Shown therein are the transmit and receive audio modules, reference clock and TDM timing control module, one of the seven TDM interface networks, and one of the seven user stations. Not shown for simplicity are the wireless and commander stations and the alarm interface. CVSD is used per proposal recommendation in a TDM Star Distribution system. The block diagram shows the preliminary breakdown of the intercom system into separate printed circuit boards. The transmit and receive audio was placed on separate cards to provide for electrical isolation. Reference clock and TDM timing control card provides common timing and control signals for the seven TDM interface network cards and the CVSD chips on the transmit and receive audio cards. The seven TDM interface cards are identical and may be interchanged. User stations are in the same way identical and may be interchanged (i.e., require no modifications or programming as to its location in the intercom system). The external station, however, will have some differences in that the controls will not be utilized.

SDM Signal Distribution

A viable alternative to TDM distribution techniques is the use of space division multiplexing, where signals are distributed on individual wirelines to the respective intercom users. This technique becomes particularly useful if the wire count can be reduced below the present 14 signal lines which are used to connect the AM-1780 and C-2297 in the AN/VIC-1 system. A SDM system was developed such that only a 10 line signal cable is required to interconnect the crew station and command station. This section presents the general details of this SDM system. The section which follows compares the relative technical performance and cost of this SDM voice distribution system versus the TDM system presented in the previous section. The design of the SDM system in this section follows the requirements set forth for the baseline system presented earlier.

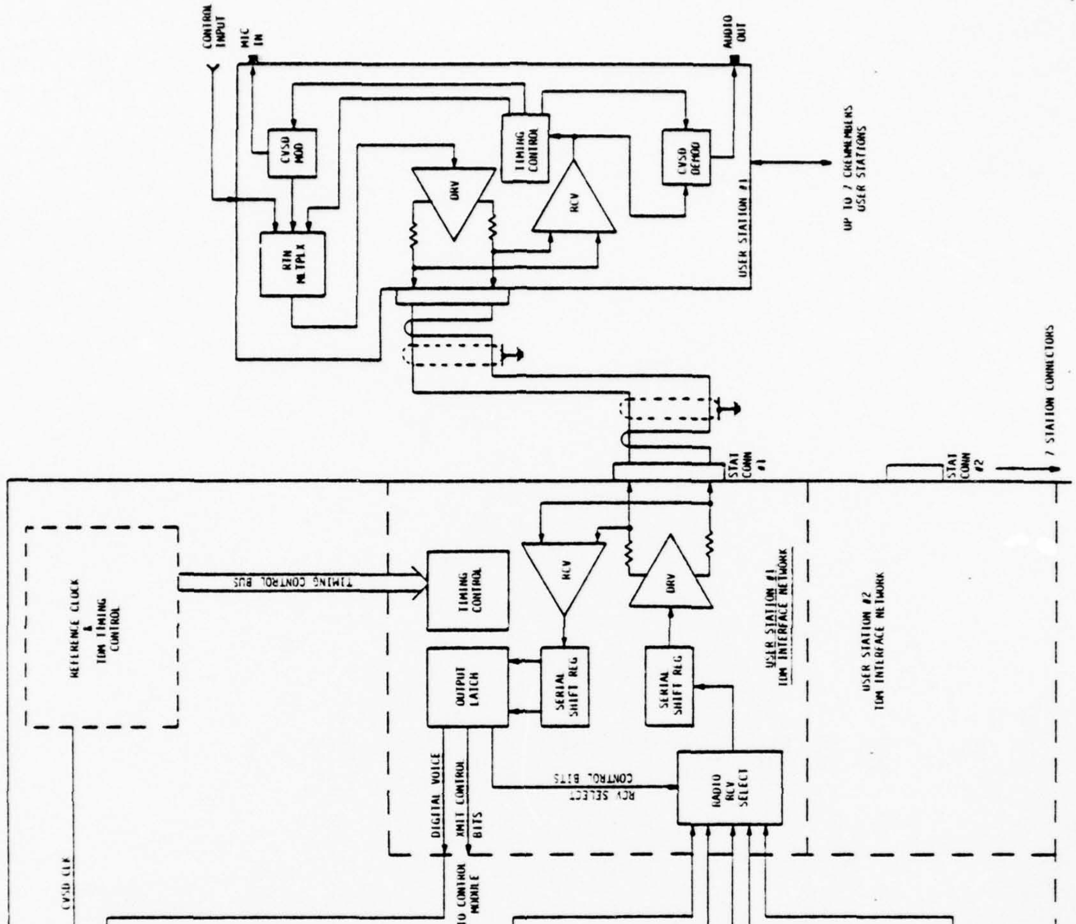


Figure 3-2. Voice Signal Interconnect Diagram for TDM Signal Distribution

A block diagram of an SDM voice distribution system is shown in Figure 3-3. It is seen that the architecture of this SDM system is very similar to the TDM system in that many of the modules and module electrical circuits are similar. The salient features of the SDM system of Figure 3-3 are:

1. Single Forward Voice Line - One of five possible intercom or radio voice signals are switched onto a single line to the user. The user selects the desired voice channel via his crew station audio select control. This control is a five position binary coded switch. The binary coded switch controls are transferred via line drivers/receivers to the crew station I/O. At the crew station I/O binary coded audio control bits control the 5-line analog switch and are also routed to the Intercom Controller, which processes the control bits prior to operation of Radio XMIT select switches.

2. Return Voice Signal - The microphone signal from each user station is routed via a balanced line to the crew station I/O. A balanced line is used to isolate power supply and forward signal ground currents from the user MIC signal. This design technique minimizes crosstalk and eliminates the leakage of RED signal ground currents onto a hot MIC line which is connected to a BLACK transmitting radio.

3. Minimal Circuitry - There is a minimum amount of electrical circuits required to transmit and receive the intercom voice signals. This is in contrast to the relatively large amount of digital IC networks required in the TDM system. In general, however, the same amount of analog amplifier networks are required in both the SDM and TDM systems.

4. Multi-Wire Cable - A 10-wire cable and associated connectors are required for routing user signals in the SDM system. This is in contrast to the 4-wire TDM cables.

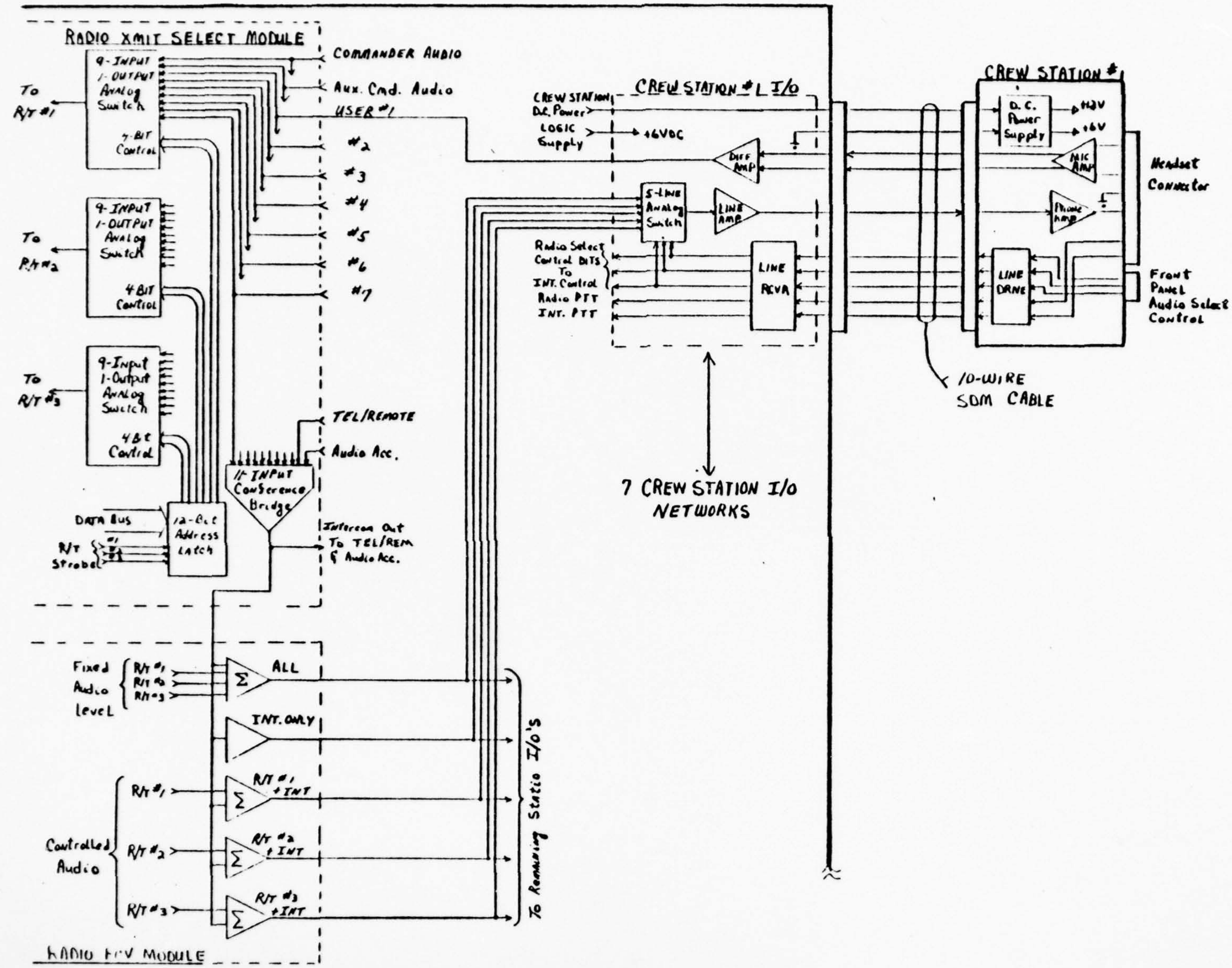


Figure 3-3. SDM Voice Distribution Block Diagram

TDM Versus SDM Performance and Cost Trade-Off

The principal technical advantages and disadvantages of TDM versus SDM signal distribution systems are summarized in the Table 3-II.

Table 3-II. TDM Versus SDM Technical Performance

Technical Item	TDM	SDM
Electrical Noise	The absolute logic levels in a TDM system provide a high degree of immunity to additive Electrical noise and crosstalk.	The analog signals in a SDM system are susceptible to additive electrical noise and crosstalk. Balanced interconnect lines can be used to reduce interference, but the cost of such balanced lines adds significantly to system cost.
Voice Intelligibility	Digital voice encoding techniques such as CVSD provide a voice quality which is equal to an analog system.	Voice quality is excellent.
Cable Size	Reduced cable size provides for ease of equipment installation. This is particularly true for the next generation intercom which must service up to 8 users.	Large cable size makes connector location difficult and cable routing cumbersome. This is particularly true of intercom intercom installation which serves up to 8 users.

The relative costs of implementing a TDM system versus an SDM system was evaluated by costing the electrical components of each approach. Only differential costs were tabulated. For instance, at the crew station each approach requires power supplies, MIC and phone amplifiers. The TDM approach, however, requires additional CVSD encoders and digital TDM circuits, while the SDM approach requires a differential analog amp and line drivers for the binary coded audio select signals. The cost of these additional circuits was tabulated for each module within the intercom system. In addition, the relative costs of connectors and cables for each approach were tabulated.

The cost differential for each approach was then calculated on the basis of these additional component costs. This calculation is summarized in Table 3-III.

Table 3-III. TDM Versus SDM Component Cost

System Module	TDM	SDM
Crew Station (I/O) 7 Modules	Additional Circuits: TDM CMOS Interface Networks Δ Cost = $35.70	Additional Circuits: Analog Switch, Line Receivers, Diff Analog Amp Δ Cost = $31.50
Crew Station 4 Units	Additional Circuits: TDM CMOS Interface, CVSD Encoder/Decoder Δ Cost = $96.80	Additional Circuits: Line Drivers and Differential Analog Amp Δ Cost = $8.00
Radio XMIT Select Module	Additional Circuits: 7 CVSD Decoders Δ Cost = $56.00	No Additional Cost.
Radio RCV	Additional Circuits: 5 CVSD Encoders Δ Cost = $40.00	No Additional Cost.
Timing Control	Additional Circuits: CMOS Timing Circuits Δ Cost = $3.40	
Connectors	4-Wire Bulkhead and Cable Connectors Δ Cost = $49.00	10-Wire Bulkhead and Cable Connectors Δ Cost = $103.48
Cable	4-Wire Shielded Cable Δ Cost = $23/100	10-Wire Shielded Cable Δ Cost = $50/100
TOTAL COST	TOTAL ADDITIONAL COST = $303.90	TOTAL ADDITIONAL COST = $192.98

The results of this cost analysis show that there is a $111 additional cost in bill of material when a TDM is implemented versus an SDM system. These costs were based on the use of MIL-M-38510, Class C parts. This was completed using price estimates in 1978. Price trends predictions for the 1980's show a relatively constant price (dicounting inflation) for analog devices used in the SDM system. The digital CMOS devices are expected to continue to decrease as the overall use of these devices increase. It is also of interest that CMOS digital circuitry can be produced as large scale integrated (LSI) circuits which for large usages is less costly, and smaller than discrete digital circuits. Analog LSI circuits, although technically possible are more expensive and have a longer development time than digital LSI circuits.

Cabling differences also enter into the system costs. The 4 wire TDM cable will certainly be less expensive that the 10 wire SDM cable. This smaller cable is also conducive to easier installation. The shell size of a 4 conductor TDM cable will be smaller than that of the 10 conductor SDM cable which will aid in connector placement on the commander's control station. Because of the numerous interface requirements of the commander's control station, a large number of connectors must be located on this component. The TDM system provides the flexibility required to develop a multi-purpose intercom system which will provide the noise immunity required for good communications. It is felt by ITT-A/OD that by early 1980's, when the VIS will be produced, a digital TDM system will also be the most cost effective.

To prove feasibility of the TDM technique, a TDM system was breadboarded for testing purposes.

One of the major advantages of the digital data transmission is its inherent noise immunity. The objective of this test is to determine how severe the noise could be on the TDM line and be able to maintain communication. It was not known how much noise the TDM system could tolerate and still have commander-to-crew station integrity.

The TDM breadboard was built to model the intercom requirements. A block diagram is shown in Figure 3-4. The crew station can select one of three inputs to the commander's station, one of which can be a headset. The breadboard is also capable of full duplex communication between the commander's station and the crew station. When the system is subjected to noise the audio signal and also the control information is affected. To maintain balanced lines, a transformer was constructed to inject noise into the line. Figure 3-5 shows the transformer and the breadboard line drivers, along with the characteristics of the transformer. It was assumed that the noise encountered in a track vehicle

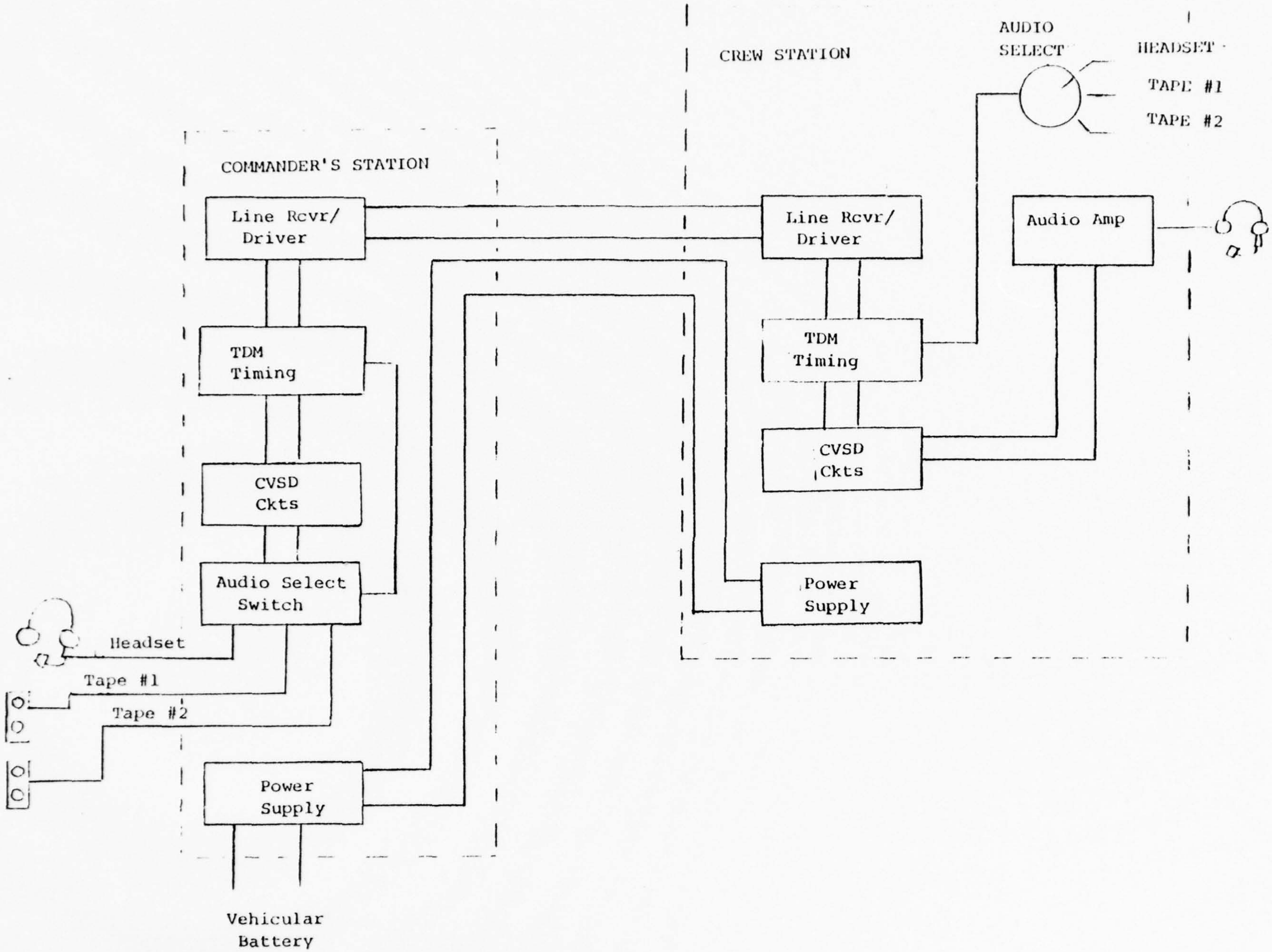
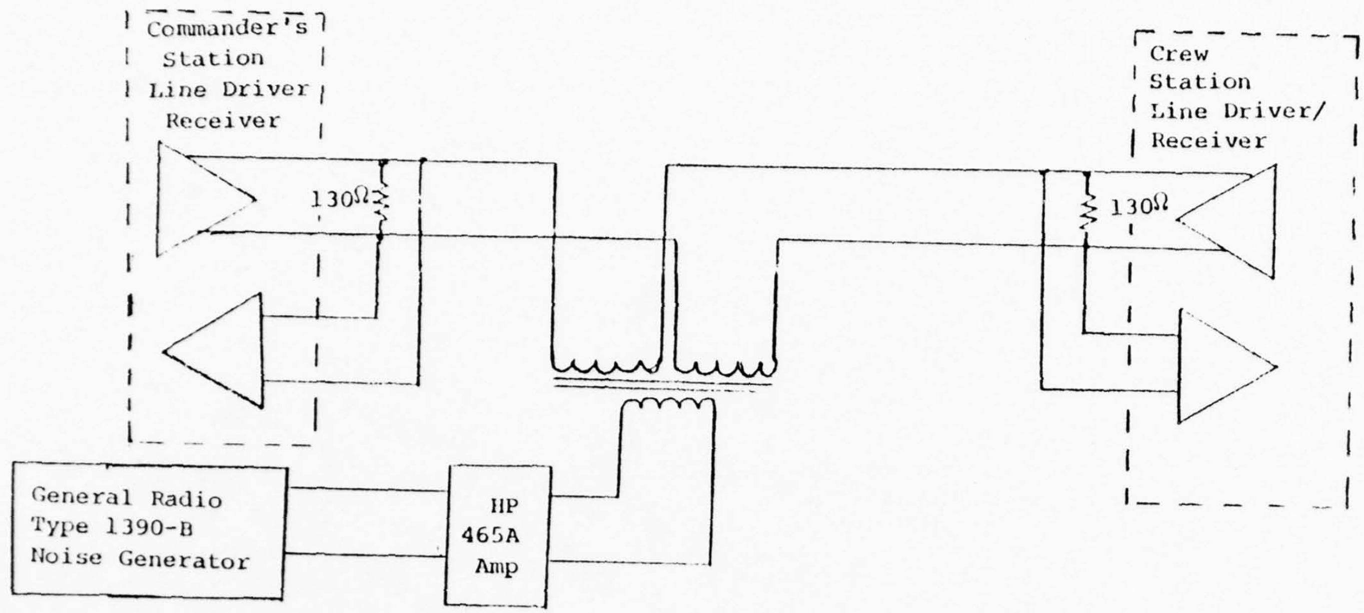
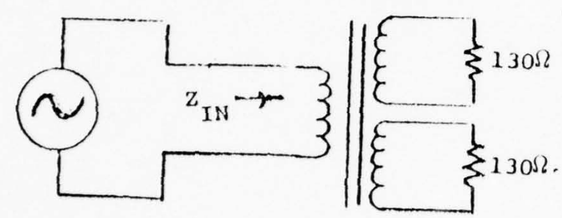


Figure 3-4. TDM Breadboard Block Diagram





TRANSFORMER FREQ. RESPONSE

30.5 kHz	REF
20.0 kHz	-.5 dB
500 kHz	-.29 dB
100 kHz	0 dB
220 kHz	-3 dB

TRANSFORMER INPUT IMPEDANCE

20 kHz	$Z_{IN} = 65\Omega$
100 kHz	$Z_{IN} = 65\Omega$
500 kHz	$Z_{IN} = 65\Omega$

Figure 3-5. Noice Insertion Technique for TDM Breadboard

would be fairly low in frequency $<$ 500 kHz. A General Radio random noise generator type 1390-B and an HP-465A amplifier were used to drive the transformer.

A 1 kHz tone was used from the command station to the crew station. With the system operating without noise, the crew station output had a SINAD measurement of 28 dB or 5 percent distortion. Figure 3-6 shows the amount of noise on the differential lines. Figures 3-6A, and C and E show the noise on each differential line when referenced to ground. Figure 3-6B, D and F show the differential concelling when the lines are referenced to one another. Figure 3-6A and 3-6B show the amount of noise required to degrade the system to 27 dB SINAD or 5.5 percent audio distortion. The high noise areas occur when the scope probe is placed on the side of the transformer which has the line transceiver in the receive mode.

Figure 3-6C and 3-6D show the amount of noise required to degrade SINAD 3 dB or (25 dB SINAD) or 6 percent audio distortion. Figure 3-6E and 3-6F show the amount of noise required to degrade the audio signal to 10 percent audio distortion. This results in a 22 dB SINAD.

When operating with very extreme noise conditions, the system would not operate at less than 10 dB SINAD at the audio output. From this test, we found that the TDM system was very tolerant to noise on the transmission line, which will result in clear, reliable communication.

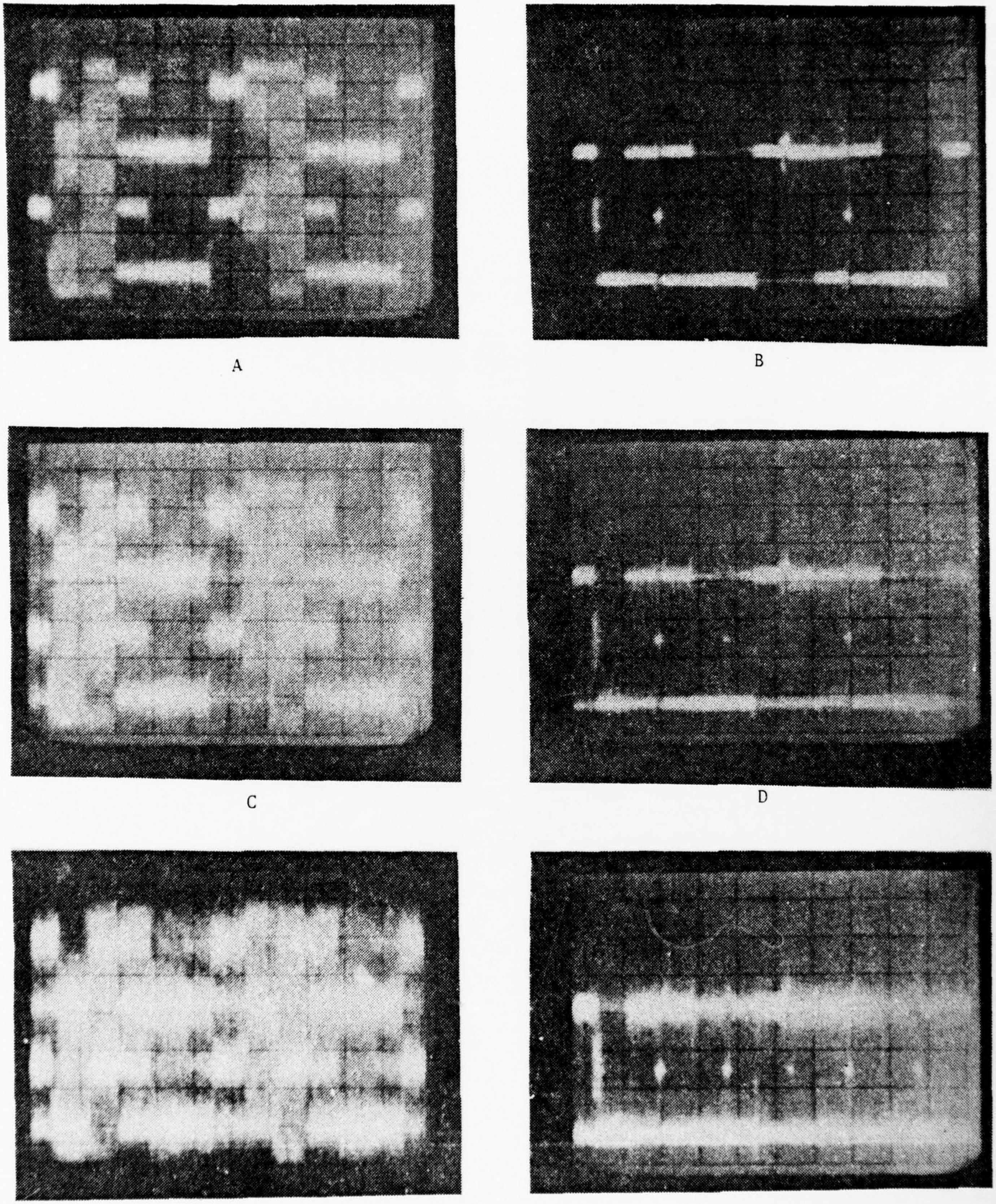


Figure 3-6. Results of Noise Tests

Continuously Variable Slope Delta (CVSD) Modulator Evaluation

The analog to digital and digital to analog conversion for the TDM system will be accomplished using a continuously variable slope delta modulator. This technique has been developed into a single integrated circuit. There are presently two manufacturers of this device and an evaluation was made as to which one would be more suitable for the VIS.

These companies and respective CDSD devices are Motorola (MC-3418) and Harris (HC-55532). The salient operating features of each circuit is summarized in Table 3-IV. From the data in this table it is seen that the Harris HC-55532 is designed specifically for operation at 32 kbps and while operation at higher bit rates is possible, the respective performance will not be optimum. The advantage of the HC-55532 is that no external components are required for its operation. The Motorola MC-3418, through the addition of external components, can be tailored for operation at bit rates from 10 kbps to 100 kbps. This flexibility of the MC-3418 provides for its superior signal-to-quantizing noise performance and excellent voice quality. The disadvantage of the MC-3418 is that several external resistors and capacitors must be added to provide this performance.

The clock rate was derived from an analysis of the Articulation Index (AI) developed by French and Steinberg. Performance bandwidth of the CVSD devices increases as the clock rate is increased. However, system considerations require that the bit rate be kept as low as possible. The Articulation Index subdivides the audio spectrum into 20 frequency bands which contribute equally to speeck intelligibility. The three upper frequency bands are: Band 18 (3650 to 4250 Hz), Band 19 (4250 to 5050 Hz) and Band 20 (5050 to 6100 Hz). If filtering is employed in the intercom system such that the audio response is reduced from 6 kHz to 4 kHz, then only three of the 20 bands will be eliminated, the truncation at the high end in combination with truncation of Band 1 (200 to 330 Hz) at the low end will reduce the Articulation Index of the system to 0.8. Voice communication systems with an AI of greater than 0.7 are considered very good to excellent in quality. The 4 kHz bandwidth can easily be achieved with a clock rate of 40 kHz which results in a 40 kbps digital output rate.

Table 3.IV. CVSD Network Operating Characteristics

	Design Feature	Motorola MC-3418	Harris HC-55532
1.	Fabrication Technique	I L with CMOS Compatible Outputs	CMOS
2.	Supply Voltage	4.75 Vdc to 15 Vdc	5.0 V to 7.0 V
3.	Min Step Size	Externally Adjustable Nom = 4 mV	Fixed Internally = 4 mV
4.	Step Size Ratio	Externally Adjustable Nom = 28 dB	Fixed Internally = 26 dB
5.	Syllabic Time Constant	Externally Adjustable Nom = 6 msec	Inversely Proportional to Clock Rate = 4 msec @ 32 kbps
6.	Low Pass Time Constant	Externally Adjustable Nom = 1 msec	Inversely Proportional to Clock Rate = 1 msec @ 32 kbps
7.	Quieting Control	Not Available	External APT Control Forces I/O Pattern during Unkeyed Conditions
8.	Step Size Algorithim	Externally Selectable a. Linear b. Exponential c. Variable attack/ delay time constant	Fixed Externally Linear
9.	Multi-Pole Feedback	Externally Selectable a. Two-Pole Integration	Fixed Internally
10.	Bit Rate	100 kbps Maximum Design parameters adjusted externally to provide optimum performance at selected bit rate	64 kbps Maximum Circuit internally designed for optimum performance at 32 kbps

A schematic diagram of a portion of the MC-3418 CVSD network and output filter is shown in Figure 3-7. In this figure, analog voice is digitally encoded at 40 kbps and the CVSD integrator output is a digitally constructed replica of the input voice

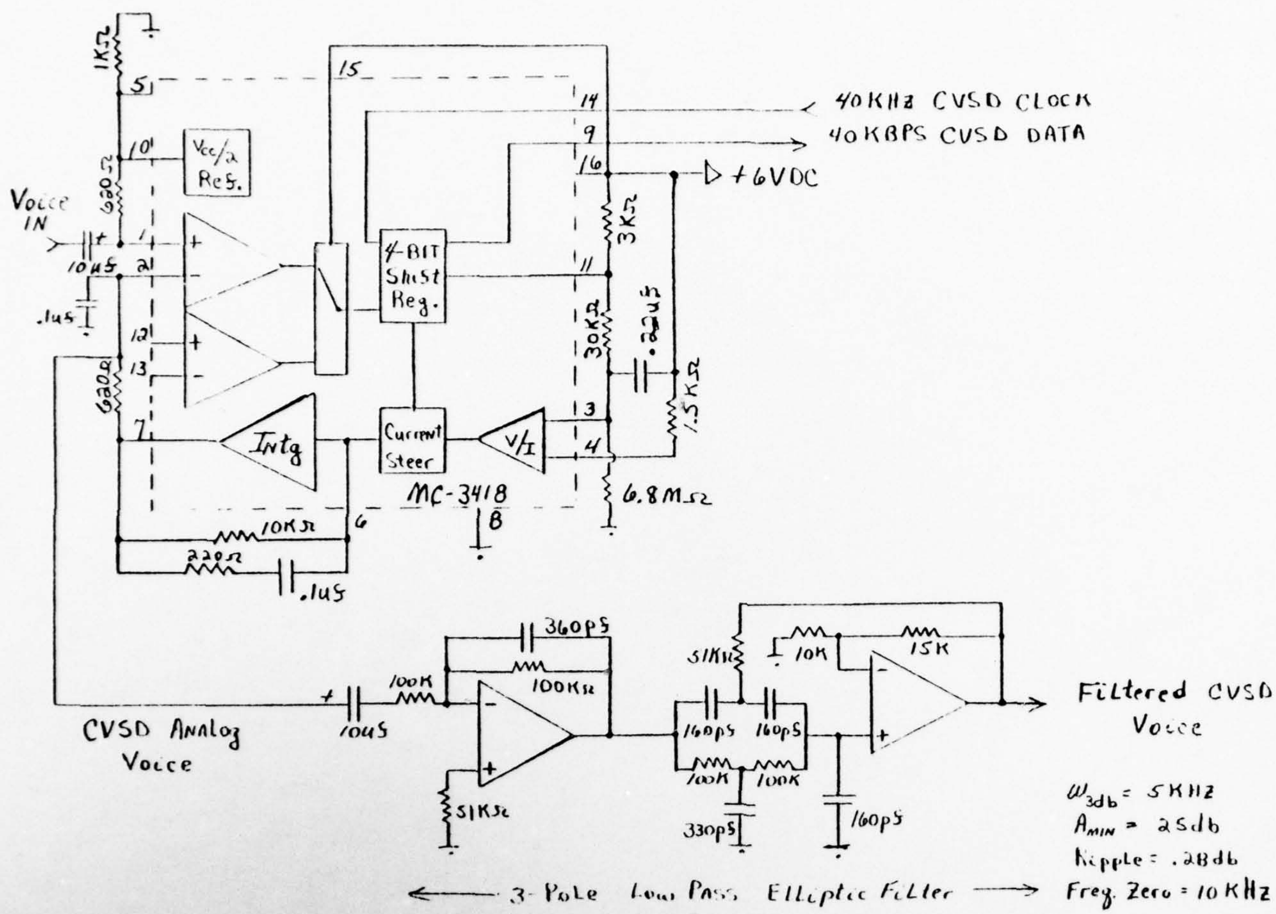


Figure 3-7. MC - 3418 CVSD Breadboard

signal. The syllabic filter and integrator time constants are determined by external resistors and capacitors. The CVSD analog voice is filtered by an active 3-pole elliptic filter. This filter provides a sharp cut-off above 5 kHz and nulls out CVSD clock subharmonics at 10 kHz.

The CVSD circuit in Figure 3-7 employs a 2-pole filter network in the integrator feedback path. Two feedback filter arrangements were tested: single-pole and two-pole. In accordance with Motorola application notes, the 2-pole filter arrangement provides about a 2 dB increase in signal-to-quantizing noise performance. The present 2-pole CVSD circuit provides a SNR of +28 dB over an input dynamic range of 12 dB. In addition it was noted that the 2-pole filter configuration decreased the metallic sound of voice signals. The Harris device does not have the facility for external feedback or optimization to a given clockrate. The input and output filters of the Harris device, however, were identical to that of the Motorola device. In the area of voice quality, the following characteristics of the CVSD network were noted:

1. Voice Intelligibility - At the high operating clock rate of 40 kHz and the operating bandwidth, the CVSD network will provide near perfect voice intelligibility performance with an articulation index of at least 0.9 or greater.

2. Voice Quality - At a clock rate of 40 kHz and an operating bandwidth of 5 kHz, there is a detectable metallic quality to the voice signal. An increase in clock rate to 50 kHz or a narrowing of audio bandwidth removes this metallic quality.

3. Speaker Recognition - Speaker recognition is excellent.

Both devices were tested with a 1 kHz test tone at various input levels and a 40 kHz clock rate. Table 3.V compares the results of this test.

Table 3-V. Comparison of MC-3814 Versus HC-55532

MC-3418		HC-55532	
Input Level	SINAD	Input Level	SINAD
100 mV p-p	23 dB		
200 mV p-p	25 dB	300 mV p-p	15 dB
500 mV p-p	27 dB	500 mV p-p	21 dB
1 V p-p	28 dB	1 V p-p	25 dB
2 V p-p	27 dB	1.4 V p-p	23 dB

The data in Table 3.V indicates that because the HC-55532 cannot be optimized for the higher bit rates, its performance is reduced from that of the MC-3418.

Also tape recorded speech was operated through both the HC-55532 and the MC-3418 and the speech quality of the MC-3418 was qualitatively better than that of the HC-55532, again because of the inability to optimize the Harris device for the higher clock rate. It was noted that even without optimization operation at 40 kHz clock rate was better than operation at 32 kHz clock rate which is the optimized frequency for the Harris device.

As a result of this test it is clear that CVSD LSI circuits will perform well in the TDM system. The Motorola device performed better than the Harris device. However, more components are required which may or m ay not be a hindrance depending on space available for CVSD circuitry.

Voice Keying Networks (VOX)

In the VIS study, several possible voice keying circuits were looked at for possible use in the intercom system. VOX circuits are being investigated for possible use within the intercom system to provide the user hands-free operation of intercom audio accessories. The use of VOX in combination with wireless intercom techniques could improve dramatically the mobility of crewmembers within armoured vehicles. The use of VOX would allow the user to devote the use of his hands to full time operation of vehicle controls. This would improve user performance in the area of vehicle operation. In selecting and designing a VOX network for operation in the intercom system, certain key operational requirements and features should be considered as follows:

1. Reliable Keying - The VOX circuit should key reliably within 50 ms of the start of a word. Rapid keying will ensure good voice intelligibility and ensure single word commands are not misinterpreted by crewmembers such that their safety is endangered. Reliable keying should be possible in adverse high noise environments.

2. False Keying - The probability of false keying should be minimal due to noise and vibration. Particular attention should be paid to designing a VOX network which cannot be spoofed by voice-like noises within the vehicle.

3. VOX Operation - Selective operation of the VOX circuit should be possible such that the user can disable the VOX at any time and operate in a manual PTT mode. The VOX network operation in Intercom Only and Radio modes should be selectable by the user.

4. Cost - The incorporation of the VOX network within the intercom system should not heavily impact the system cost. The circuit design should be simple and economical. Consideration should be given to making the VOX circuit an optional crew station feature, which is installed only at those crew stations which require VOX operation. Operation of VOX as an optional add-on module or plug-in PC board would reduce significantly the cost impact on the system.

Five VOX networks were investigated for possible use within the intercom system. These networks were as follows:

1. Fixed threshold voice detection and keying network

2. Adaptive threshold voice detection and keying network.

3. CVSD pattern detection and key network

4. Radiometer or energy comparison voice detection and keying network

5. Zero crossing voice detection and keying network

In the above approaches, breadboard models of networks 2, 3, and 4 were built and tested. The fixed threshold approach was not built since it could easily be evaluated by disabling the adaptive operation of network 2. The zero crossing detection approach was not built since its operation closely resembles the operation of network 4 in that both techniques measure the frequency content of the voice signal to detect its presence.

The relative performance of the three VOX networks, which were breadboarded, were evaluated by measuring the attack time of each network for various word inputs. Their false keying performance was also evaluated under high background noise conditions. The adaptive threshold VOX network offered the best attack time of 17 ms average for a 26 word vocabulary. The attack time for all words was less than or equal to 50 ms. It was also immune to false keying at peak voice to RMS noise ratios of 10 dB. The radiometer VOX network offered the next best performance with an average attack time of 34 ms for a 26 word vocabulary. The radiometer VOX network, however, was unable to detect rapidly words that begin with a "s" sound such as in the word SIERRA. The radiometer VOX network also provided excellent false keying performance. The performance of the CVSD pattern detection VOX was very poor in terms of attack time, in that certain words were totally missed. No extensive data was taken on this VOX network.

The following subsections present a description of each of the VOX networks tested and a summary of their relative performance is then presented.

Adaptive Threshold VOX

A block diagram of the adaptive threshold VOX network is shown in Figure 3-8. The implementation of this VOX network is similar in concept to the digital voice activated switch developed at COMSAT labs.[1] An adaptive threshold VOX network was chosen for testing in preference to a fixed threshold VOX network, due to the following limitations inherent in a fixed threshold VOX:

1. Noise Immunity - To provide good noise immunity and prevent constant false keying, the voice detection threshold must be set high. Under varying noise levels common in a vehicle, the voice threshold is always set at the highest level for worst case noise levels.

2. Voice Detection - Voice detection for a fixed level VOX is at best marginal since the threshold is set to a high level which avoids false keying in high noise environment. Under quiet conditions the user must still shout to key the VOX. Even when shouting words which begin with "s" sounds such as "Sierra" will not key the VOX network.

The adaptive threshold VOX overcomes these shortcomings and provides an optimum voice threshold level under a wide range of varying noise levels. In Figure 3-8, the voice signal from the users MIC amplifier is rectified and fed to two level detectors. At the noise threshold level detector a tracking D/A converter is used to track the noise peaks. The time constant of the integrate and dump (I&D) network is set such that if the incoming noise peaks exceed the noise tracking voltage more than 10 percent of the time, the up-down counter is incremented and the respective D/A

[1]Jankowski, J.A., "A New Digital Voice Activated Switch", COMSAT Technical Review, Vol. 6, No. 1, 1976.

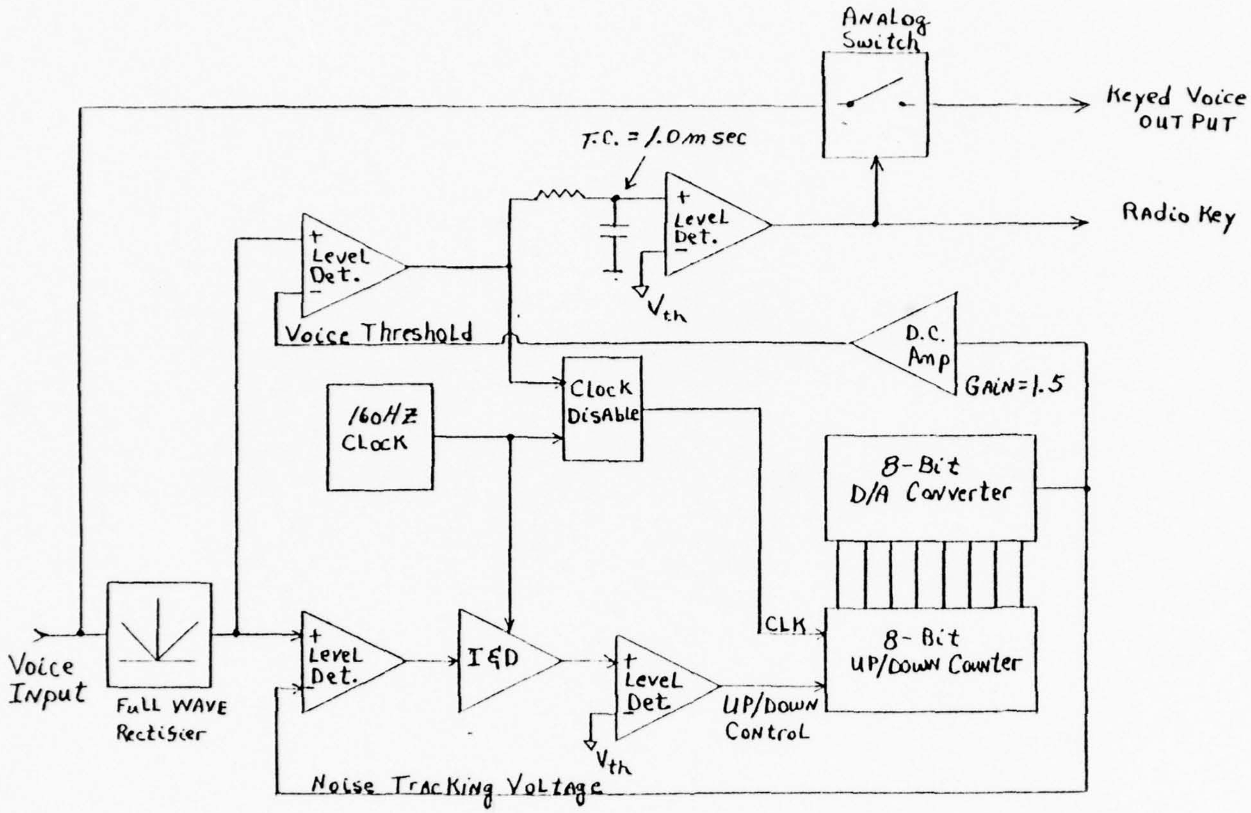


Figure 3-8. Adaptive Threshold VOX Network

noise tracking voltage is increased. The D/A converter is updated at a 160 Hz rate unless the voice threshold level detector is triggered. The presence of voice signals thus disables operation of the up-down counter. The voice threshold voltage is always 50 percent higher than the noise tracking voltage. This ratio of noise and voice thresholds prevents false keying by noise peaks but is very sensitive to incoming voice signals. The adaptive VOX network in Figure 3-8 provides the following key operational features:

1. Update rate of 160 Hz provides for rapid tracking by D/A converter of noise levels within vehicle.

2. Updating of D/A converter is disabled during active voice periods such that threshold level is held constant during periods of voice activity.

3. The voice threshold level is always set at the optimum level for detection of voice signals. This level provides a low false keying rate due to noise, but allows the detection of low level voice sounds such as present in the word "Sierra".

Radiometer VOX Network

A block diagram of the radiometer VOX network is shown in Figure 3-9. The principle of operation for this VOX network is based on the relative spectral shape of voice signals versus interferring noise. The spectrum of the typical male voice rolls off at about 10 dB/octave from 500 Hz to 4000 Hz. During speech periods, the amount of detected energy in filter band from 300 Hz to 1500 Hz is much higher than the voice energy in a 1500 Hz to 2500 Hz frequency band. This fact can be used to detect the presence of a voice signal. During non-voice periods, the input to the radiometer VOX network is background noise interference. If the noise spectrum is flat and the noise bandwidth of the two radiometer filters are equal, then the VOX network will not be triggered. Good false keying performance for the radiometer network is dependent on the input noise being flat noise. The interferring noise spectrum within the M113A1 vehicle is not flat but is very similar in shape to the voice spectrum. The M113A1 noise spectrum is flat in nature after being passed through the noise cancelling microphone. This fact results in the requirement that proper operation of a radiometer VOX within an armoured vehicle will depend to a high degree on the performance of the noise cancelling microphone. Preliminary tests of a radiometer VOX and noise cancelling microphone were performed in the lab using the noise environment test setup shown in Figure 3-10. Test results

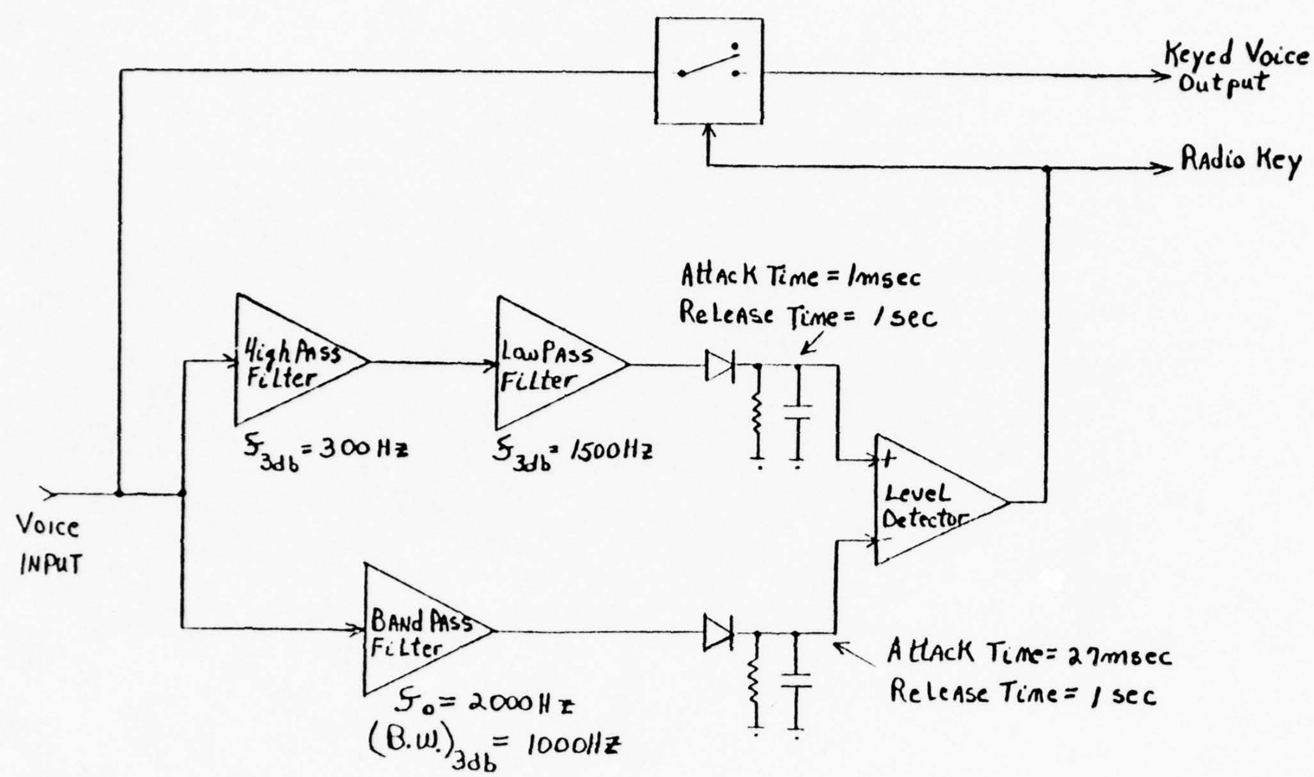


Figure 3-9. Radiometer VOX Network

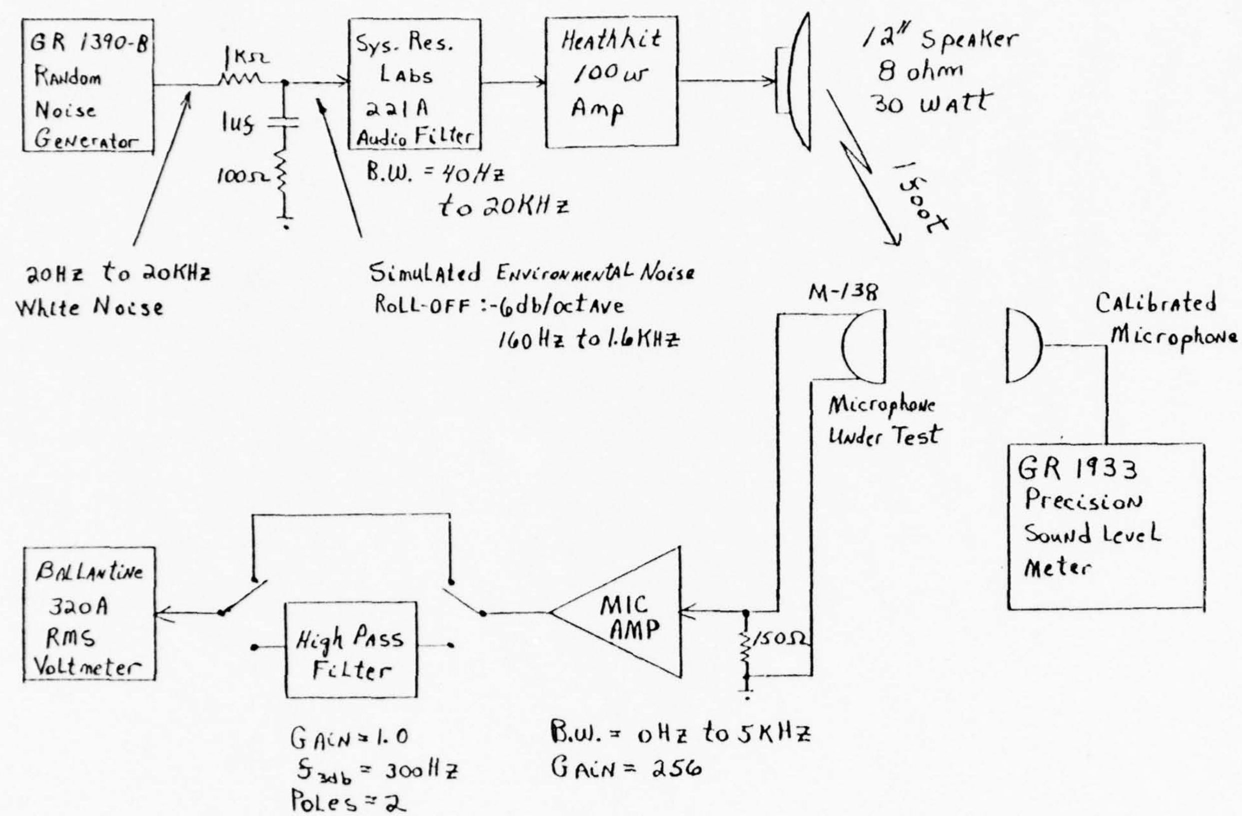


Figure 3-10. Environmental Noise Test Setup for Evaluating Noise Cancelling Microphone

showed that the radiometer VOX was immune to false keying at noise levels up to +110 dB when operating with the Telex CS-61 headset microphone.

In general the radiometer VOX provided fast attack times, but for certain sounds the performance was marginal. This was particularly true of unvoiced sounds such as "s" which starts words such as "seek", "Sierra", etc. Words such as these suffered severe front end truncation. This poor performance is due to the fact that the frequency content of these sounds is in the range of 2000 to 3000 Hz. Also, these sounds are very noice-like in nature and cannot be distinguished from background noise interference. As a result of evaluating the radiometer VOX network, the following operating advantages and disadvantages were noted:

1. Simple Hardware - The radiometer VOX can be implemented with very simple hardware with respect to the Adaptive Threshold VOX.

2. Good Immunity to False Keying - If the interferring background noise spectrum is flat in nature, the radiometer VOX offers good immunity to false keying. Low frequency noise would degrade performance.

3. Marginal Attack Time - The radiometer is unable to detect certain high frequency components of certain words. This results in the truncation of the front end of these words and can lead to misinterpretation of the word.

CVSD Pattern Detection VOX

Due to the fact that CVSD is being considered for encoding/decoding of analog voice in an Intercom TDM voice distribution system, it was decided to investigate whether bit patterns existed in the CVSD output data stream which were indicative of voice activity versus input noise interference. The digital output of a CVSD encoder generates a random output bit pattern, but this pattern is characterized by long series of 1's and 9's during high amplitude voice inputs. During the input of low level voice signals or noise-like signals, the CVSD digital output is characterized by alternating patterns of 1's and 0's.

A simple variable length shift register and AND gate decoder network was set up at the output of the MC-3418 and CVSD encoder. The decoder could be set to detect consecutive patterns of 1's or 0's from 4 bits to 8 bits in length. Test results showed that a decoder setting of six consecutive logic 1's or 0's was necessary to provide immunity to false keying on noise. With this decoder setting the pattern detection method worked reliable for words which began with hard consonant sounds such as "dog," "gun", etc. The pattern detection network, however, failed to detect such words as "these," "shoot," and other words which do not exhibit low frequency high amplitude characteristics. Extensive testing was not performed on this VOX network because of its poor performance with certain words.

VOX Network Evaluation and Testing

Tests were made to evaluate the attack time performance of the Adaptive Threshold and Radiometer VOX. These tests included a 26 word vocabulary test to measure average attack time and to determine the existence of words which posed particular detection problems. Test tapes were run to provide a subjective evaluation and noise interference tests were made to evaluate false keying performance. Also evaluated was the dynamic voice range over which each VOX network would reliably be operated.

To test the attack time of each VOX network, the 26 word international word-spelling alphabet was used. Its choice was convenient and purely arbitrary. Whether the use of this particular word list is optimum for testing VOX networks is not known. It is felt that this word list covers most typical voice sounds which might eventually key up an Intercom VOX network.

The results of attack time tests for the two VOX networks is shown in Table 3-VI. These test results show that the Adaptive Threshold VOX provides much better performance than the radiometer network. The effect of front end clipping on voice intelligibility has been evaluated by Ahmed and Fatechard. [1] Their work showed that front end clips of up to 30 ms are acceptable for plosives and fricatives (i.e., plosives are words such as "bravo" and "papa", while fricatives are words such as "foxtrot" and "victor". For these words, both VOX networks were within the 30 ms except for the word PAPA. Ahmed and Fatechand also found that clips of up to 40 ms were acceptable for semi-vowel sounds while clips longer than 50 ms will significantly reduce articulation scores. On the basis of criteria set up by Ahmed and Fatechand it is felt that the Adaptive Threshold VOX provides acceptable performance, while the Radiometer VOX is marginal to unacceptable in performance.

A subjective analysis of the two VOX networks was made by playing a test tape of the 26 word vocabulary through

[1] Ahmed, R. and Fatechard, R., "Effect of Sample Duration on Articulation of Sounds in Normal and Clipped Speech", Journal of Acoustical Society of America, Vol. 31, 1959, pp 1022-1029.

Table 3-VI. VOX Network Attack Time Performance Test

Test Mode	Adaptive Threshold VOX Attack Time (ms)	Radiometer VOX Attach Time (ms)
1. Alpha	5	10
2. Bravo	10	20
3. Charlie	20	60
4. Delta	10	20
5. Echo	5	5
6. Foxtrot	20	30
7. Golf	20	10
8. Hotel	30	50
9. India	10	20
10. Juliet	40	50
11. Kilo	10	50
12. Lima	20	40
13. Mike	5	5
14. November	5	10
15. Oscar	5	20
16. Papa	50	50
17. Quebec	50	40
18. Romeo	10	30
19. Sierra	30	140
20. Tango	20	70
21. Uniform	10	60
22. Victor	10	25
23. Whiskey	10	20
24. X-Ray	5	5
25. Yankee	20	50
26. Zulu	50	70
AVERAGE ATTACK TIME	$T_{avg} = 17$ ms	$T_{avg} = 35$ ms

each VOX and then listening to the VOX output. In general, the subjective evaluation confirmed the attack time test results. All words passed through the Adaptive Threshold VOX were heard correctly while the word "Sierra" was heard incorrectly with the radiometer VOX.

Additional tests were run on both VOX networks to evaluate performance in a high noise background and over a wide dynamic voice range. Both VOX networks operated reliably without false keying at voice peak-to-RMS-noise ratios of 10 dB or less. Each VOX network was also capable of operation over an input dynamic range of 20 dB.

The use of a VOX network in the intercom system remains to be determined at this point in the study. Results to date show that an adaptive threshold VOX provides acceptable performance when operating in a noisy environment characterized by flat noise. Questions which remain to be answered on the application of a VOX network in intercom systems are listed as follows:

1. Environmental Noise - False keying performance has been evaluated in the lab with conventional test equipment. Although performance was good, the VOX network should be evaluated in a real-world vehicle operating environment to assure there are no unique vehicle noise characteristics which cause false keying.

2. User Safety - In the day-to-day operation of an army vehicle, there are one word commands among crewmembers which coordinate the operation of the vehicle. The safety of the crewmembers depends on reliably receiving these commands. Truncation of key command words by the VOX network could lead to word misinterpretation. This could pose a safety problem within the vehicle. Command words such as "power" prior to turret rotation must be received correctly by each crewmember such that hands are in a safe position during turret rotation. Such safety considerations with respect to use of a VOX must be discussed with the user.

3. Cost Effectiveness - It remains to be determined if the mobility provided the user by the VOX is significant with respect to added system cost.

Control Techniques

The VIS has an expanded control requirements over that of the AN/VIC-1 equipment. This control will be locted in the commander's control station and the intercom/radio functions which must be controlled as follows:

1. Radio Controls - Front panel switches are provided on the intercom commander's control station for operating up to three vehicular R/T units. Controls include: frequency presets, RF power select, ECCM, PT/CT. In SINCGARS-V radio.

2. Crewmember Station Control - The operation of crewmember stations must be monitored and controlled by the commander's control station. Functions to be controlled include: radio access, external station intercom/radio access and alarm distribution.

3. Auxiliary Command Station - Provisions must be made for connection of an auxiliary command station to the commander's station such that a second crewmember can have access to control of the vehicular radios by the primary and auxiliary command station.

A block diagram is shown in Figure 3-11, which illustrates the present assessment of control functions which must be processed by the intercom commander's control station. In this diagram it is seen that control busses distribute and collect control information from four areas: crewmember stations, vehicular radios, commander control station front panel, and XMIT audio module. The processing of this information is provded by the controller I/O and central controller unit of Figure 3-11. The electrical design of these control networks must provide an efficient I/O which minimizes interconnect wires and control circuits which minimize hardware. Two approaches to the design of these I/O and control circuits have been studied and these are:

1. Discrete I/O under control of a dedicated discrete logic network.

2. Discrete I/O which can be combined into an integrated control subsystem under microprocessor control.

In Figure 3-11, it is necessary for the controller I/O to provide the following interface functions:

1. Front Panel Controls - 15 lines of discrete control information must be processed and routed to respective radio and intercom control outputs.

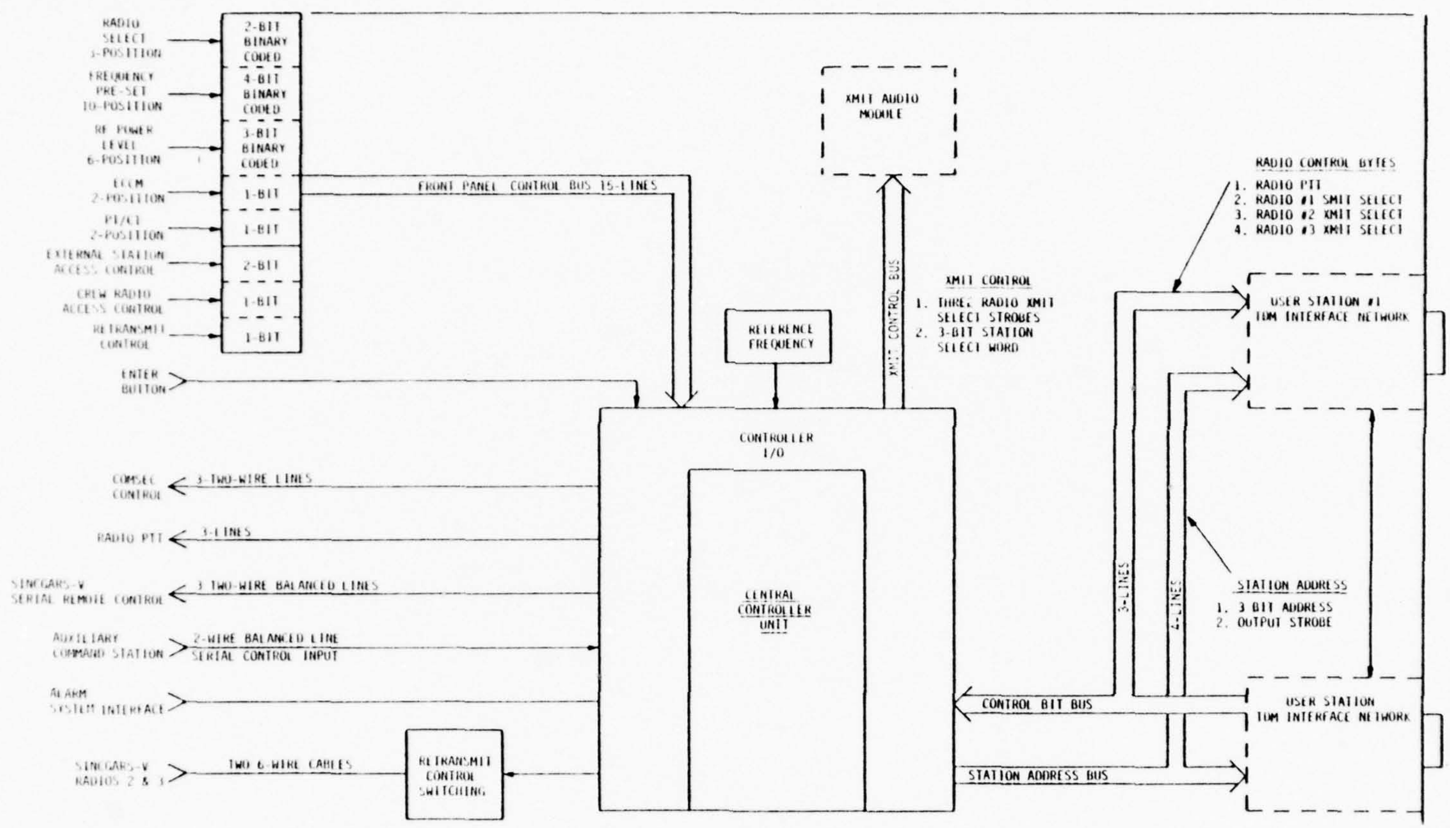


Figure 3-11. Control Signal Interface Diagram

2. Crewmember Station Radio Control - Radio control bytes from the crewmember stations are received via the TDM interface. These control bytes must be processed and then routed to the XMIT audio module which selects the appropriate radio for transmission. Also, the PTT control bit is routed to the respective radio depending on the position of the command station access control switch.

3. Radio Control - Three 2-wire serial output lines are provided for transferring command/control information to the SINCGARS-V radios.

4. Auxiliary Command Station - A 2-wire serial input is provided to accept radio command signals from an auxiliary command station.

5. XMIT Audio Module - Three 8-to-1 multiplexers provide for routing user voice signals to radio XMIT ports. A three bit station select word is strobed into the multiplexers by one of three separate radio XMIT select strobes.

Of the two circuit approaches considered for implementing these control I/O functions, the following advantages and disadvantages are considered in Table 3-VII.

The trade-off analysis in Table 3-VII clearly points out that the lower cost, smaller size, and flexibility of a microprocessor control approach is the optimum method of control for the intercom system. The following paragraphs described in some detail I/O and control approaches which will be implemented using a microprocessor. Functions to be controlled by a one chip microprocessor in the intercom system are summarized as follows:

Front Panel

Intercom control switches are binary coded. Refer to Figure 3-11. The microprocessor scans every 10 ms the following four switches: retransmit, radio access, enter, and external station. If the enter switch was pressed, the following switches are sampled to be stored for transmission to the radio: radio select, presets, RF power level, ECCM/normal, and CT/PT. The switches not used by the microprocessor are as follows: power, radio power, intercom accent, and commander's headset controls.

Table 3-VII. Discrete Versus Microprocessor Control Approach

Criteria	APPROACHES Approach 1 Discrete I/O Under Discrete Logic Control	Approach 2 Discrete I/O Combined with Microprocessor Data Bus I/O & Microprocessor Control
1. Circuit Complexity	1. Relatively simple gate, shift register and counter configurations can provide for the design of I/O and control functions.	1. Relatively simple microprocessor configurations consisting of a processor, RAM and ROM network can provide all control functions and several I/O functions. Discrete I/O circuits are provided where necessary
2. Size	2. Although the complexity of the discrete design approach is relatively simple, the large number of gates and shift registers results in a very large control network.	2. The use of a one-chip microprocessor results in a very small physical size for the control network.
3. Cost	3. The large number of discrete control circuits results in high assembly cost during production.	3. The use of a microprocessor reduces assembly costs in production.
4. Flexibility	4. Changes in intercom control functions require modification of actual circuits and is	4. Changes in intercom control functions can be accomplished through simple re-programming and is inexpensive.

SINCGARS-V Radios

When the front panel control microprocessor subroutine has indicated a change in radio operation, the radio interface subroutine is called. The radio update information is then formatted into a Universal Asynchronous Receiver Transmitter (UART) format (i.e., start, stop, and parity bits are added). An external reference clock is then used to transmit information to the SINCGARS-V radios. The microprocessor then looks for the valid receive word back from the radio. The operator will be alerted if an error should occur in transmission.

Radio transmit control involves three separate I/O ports. Referring to Figure 3-11, the microprocessor is informed of transmission requests by users through the TDM interface network. The microprocessor enables each TDM network, one at a time, to send its control bits over the control bit bus. The control bit bus is shared between all TDM networks. If there are any conflicts in requests, the microprocessor decides who has priority. Once informed of the request, the microprocessor strobes the XMIT audio module with the 3-bit station select word so as to connect the individual user audio with the radio. The third I/O port sends PTT information.

Auxiliary Commander's Control Station

When the auxiliary station is connected to the commander's station, a pin is grounded notifying the microprocessor to check the auxiliary serial port for a transmission from auxiliary control. If a transmission is received, then the controls are updated. If the microprocessor is not in the process of receiving a transmission from the auxiliary unit, the front panel of the commander's station is scanned. If switches have been changed, operator control is transferred back from the auxiliary to the commander's station. Transmission over the auxiliary serial link is in a digital UART format. This results in a reduction in software. The same UART subroutines used for SINCGARS-V radios can be used for the auxiliary link.

A microprocessor based central controller design was completed. The work resulted in hardware selection and basic interconnect diagrams along with general flow charts. The flow charts detail computer program flow and given an indication of memory requirements and execution times.

In the hardware implementation, an RCA COMSAC microprocessor, CDP1804, was chosen. This microprocessor offers a low cost, small package system because CPU, ROM, and RAM are in one chip. This device will start in production during the fourth quarter of this year and is expected to be military approved shortly thereafter. If problems should develop with military qualification, the 1802 is pin-for-pin compatible with the 1804 and software could be modified so as to use only a ROM and only internal CPU registers. This would eliminate the need for read/write memory RWM. The 1802 is expected to be military qualified by the end of this year.

The 1804 has on chip 2K of ROM, 64 bytes of RAM and an 8-bit timer. It is an 8-bit SOS/CMOS microprocessor. Referring to Figure 3-12, the inputs from front panel switches of the commander's control station are sampled using tri-states to gate the information into the microprocessor. Debouncing of switches is provided for in software. R/T status information is stored in one byte of RAM for each R/T and can be output directly without reformatting to the displays using only one output command. This is possible because preset requires three bits, RF power requires three and ECCM and CT each require one bit, making the total eight bits or one byte. COMSEC is controlled by three lines which control switches to turn the COMSEC units to CT. Three bits of the same latch control R/T press-to-talk. One bit of the latch controls retransmit.

The four bit latch controls the situation of which R/T or auxiliary the digital line drivers and receivers are connected to. Software simulates a universal asynchronous receiver transmitter (UART) using the Q flipflop in conjunction with a digital line driver and a line receiver feeding into the microprocessor using EFI. One bit of the eight bit latch controls the gating of a tone generator onto the digital line so as to signal the R/T that a control message will follow.

Crewmember and commander PTT control is provided for by the microprocessor. When a crewmember requests to transmit, the TDM networks provide the microprocessor with this information along with which R/T was selected. The microprocessor then transfers the TDM station number to the appropriate R/T multiplexer in the transmit audio module. Timing diagrams for TDM and XMIT AUDIO interfaces are shown in Figures 3-13 and 3-14.

Software flow charts are given in Figure 3-15. These flow charts would later lead to a more detailed flow chart and then to assembly language code. A detailed flow chart should not be started until the advanced development stage (which results in deliverable hardware) because minor details of the system may change. This would require a new detailed flow chart.

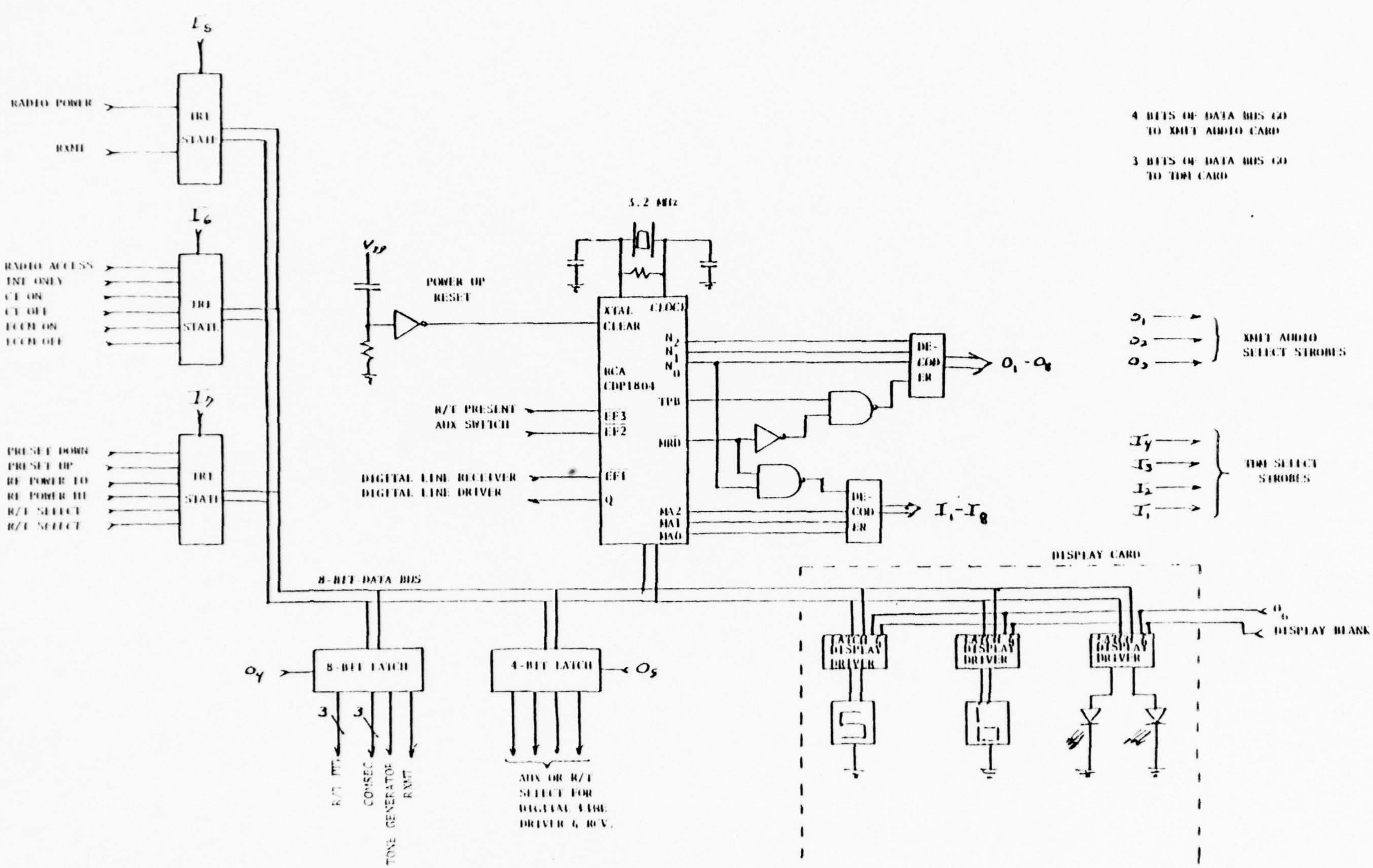


Figure 3-12. Central Controller Using RCA-1804 Microprocessor

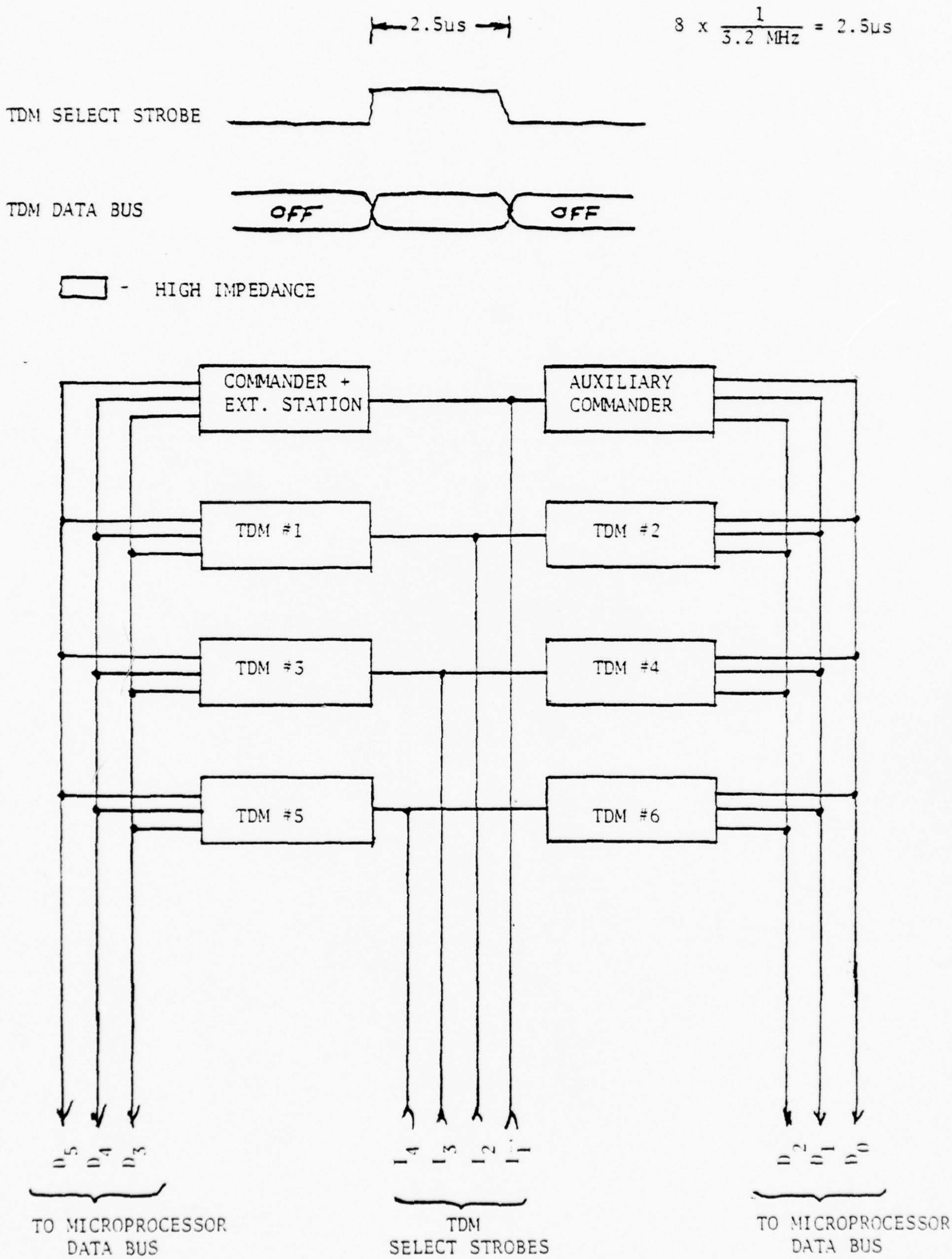
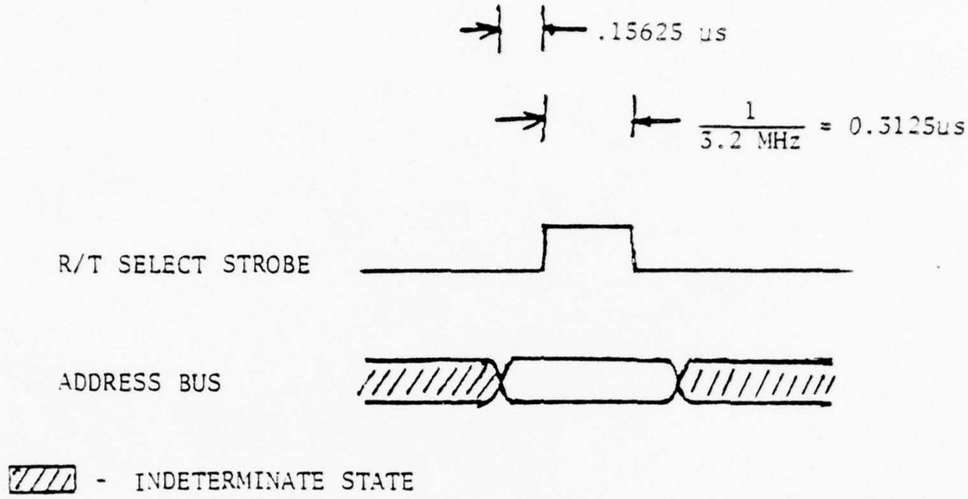


Figure 3-13. TDM Timing and Wiring Diagram



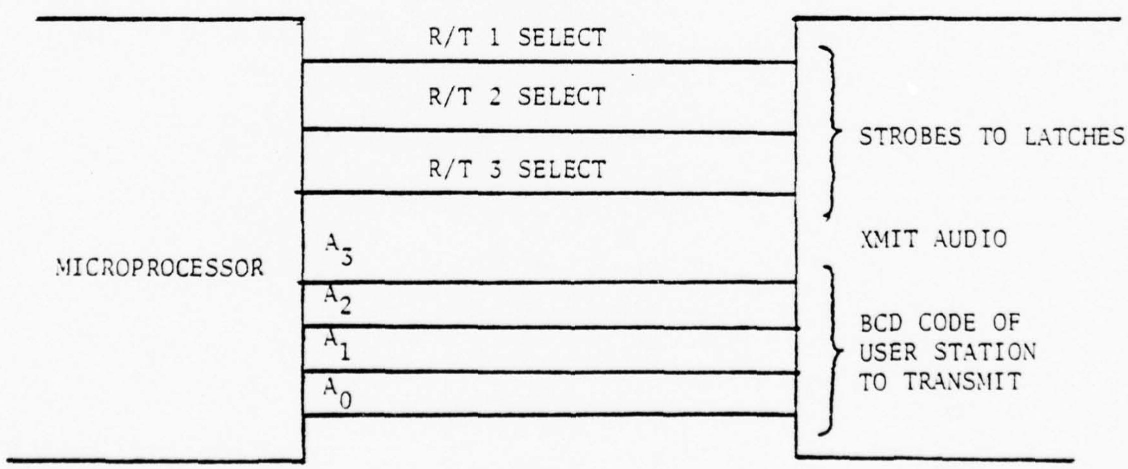


Figure 3-14. Transmit Audio Timing and Wiring Diagram

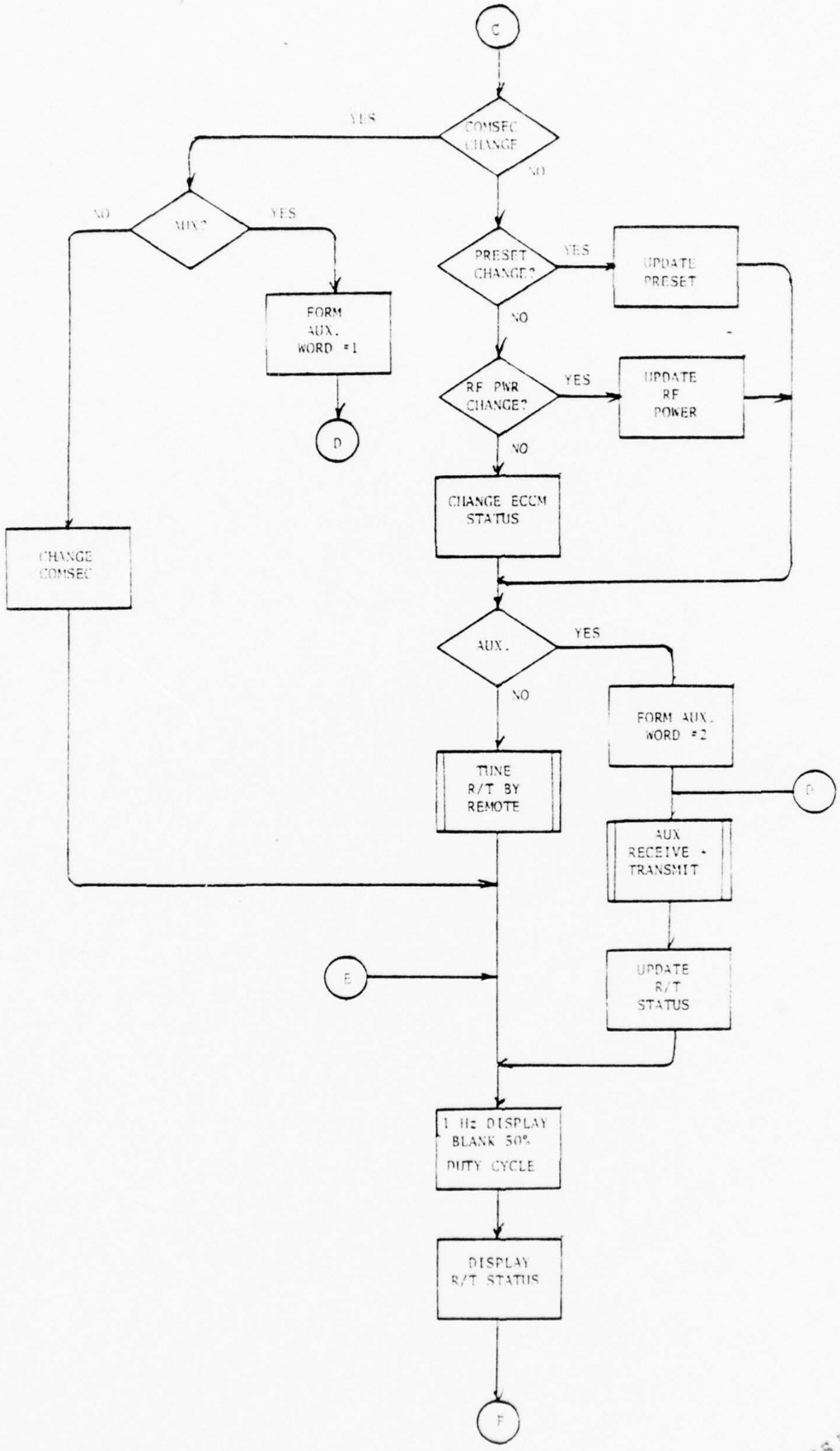


Figure 3-15. General Flow Chart for Central Controller (Sheet 1 of 3)

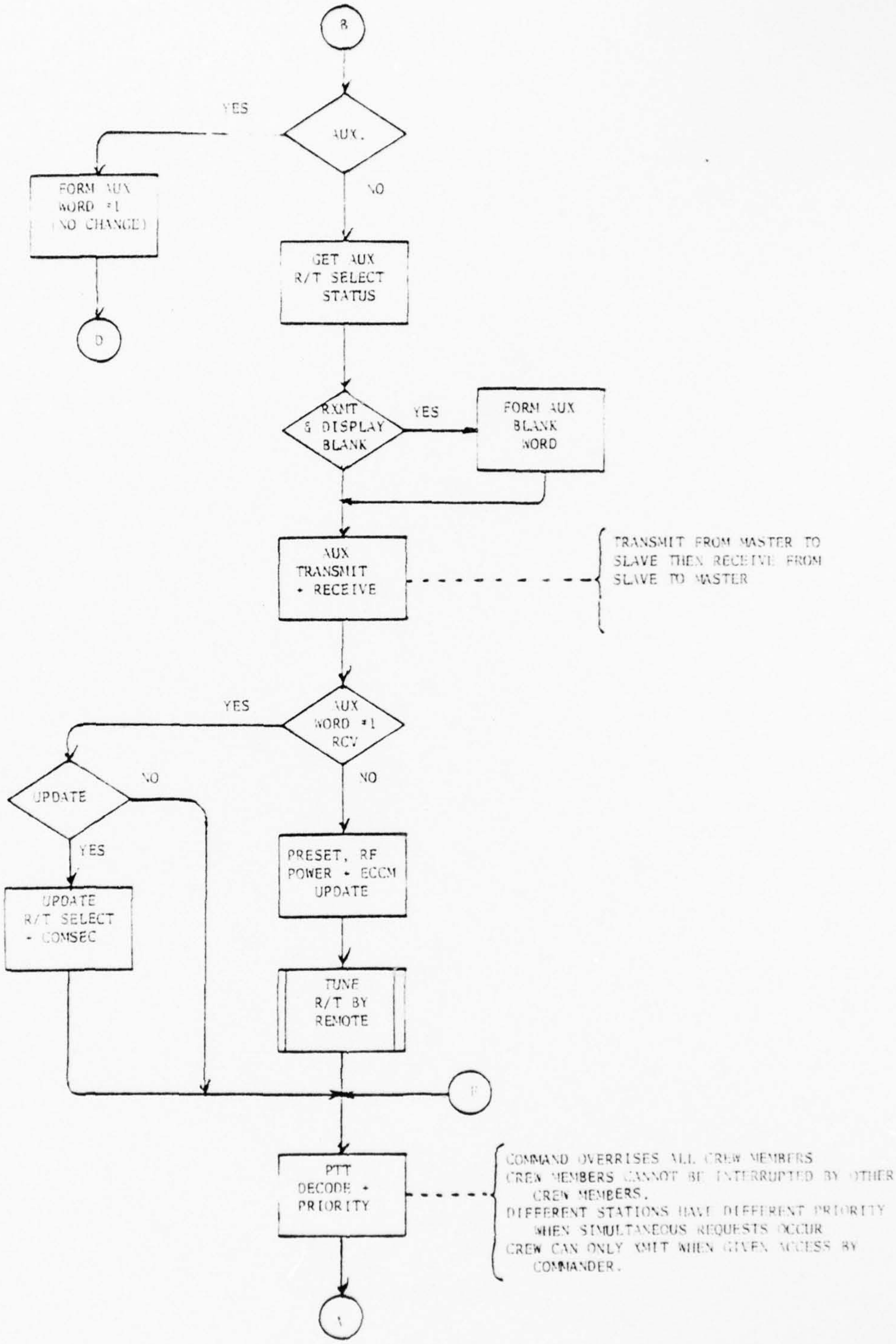


Figure 3-15. General Flow Chart for Central Controller (Sheet 2 of 3)

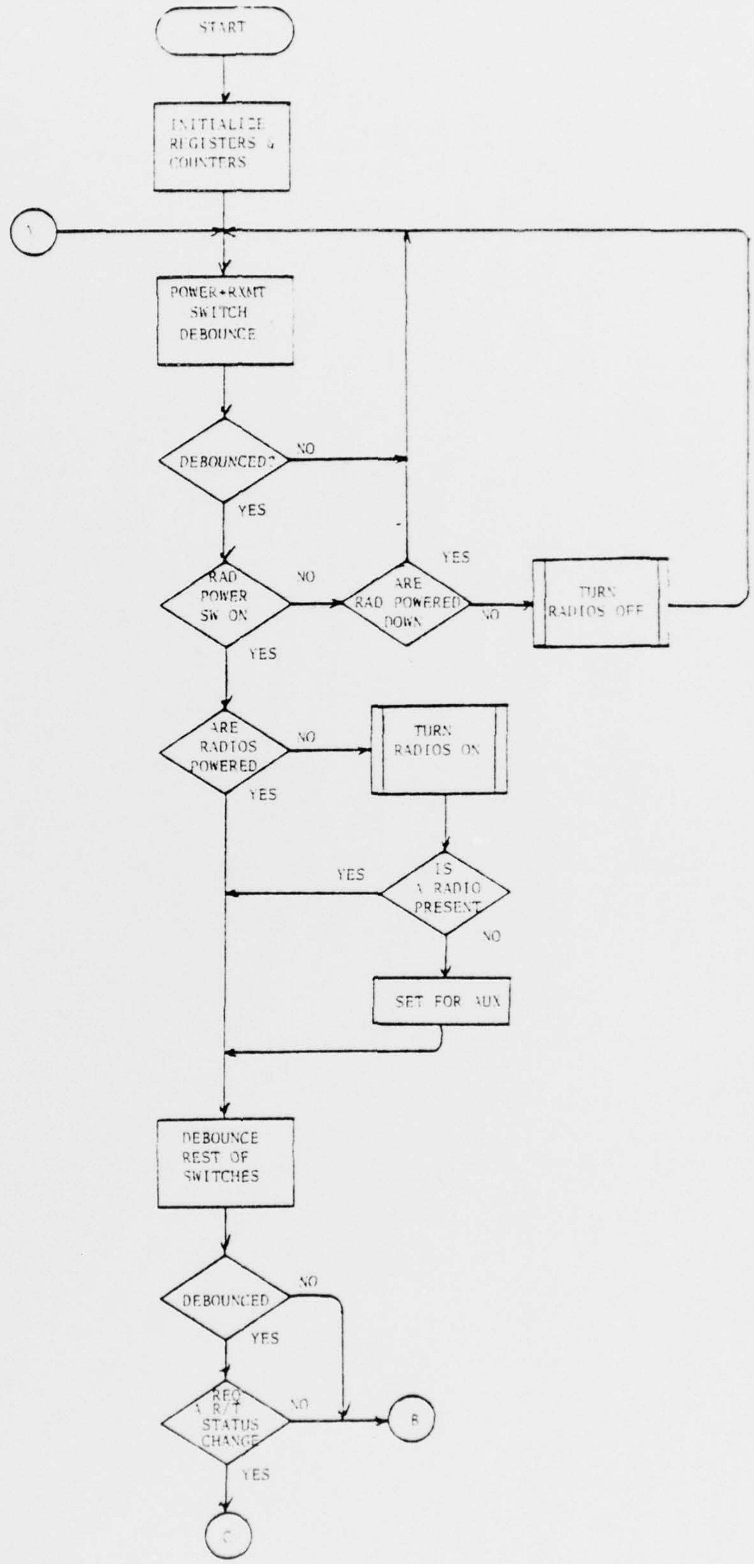


Figure 3-15. General Flow Chart for Central Controller (Sheet 3 of 3)

For control of SINCGARS-V radios, the microprocessor must transmit and receive eight UART words. Each UART word contains eight information bits plus one start and one stop bit. The protocol of controlling a R/T remotely is explained in detail in Volume 2 of ITT-A/OD's SINCGARS-V proposal. The auxiliary station will use the same UART subroutines as the R/T. Bit definitions are given in Table 3-VIII.

Front panel operation was explained in the Second Quarterly Report. Two things should be repeated from this report. First, in retransmit mode, if the commander is displaying a retransmit radio status, his display will flash at a 1 Hz rate. Second, if a SINCGARS-V radio should fail to tune remotely, zeros will be displayed in the preset and RF power displays.

The microprocessor software simulates a UART using the 8-bit programmable timer for timing. The UART format is used for remote operation of R/T and auxiliary commander's station interface. The R/T UART bit definition and synchronization schemes are given in Volume 2 of ITT-A/OD's SINCGARS-V proposal. If an error should occur in UART transmission, the software will detect this and display zero for preset and RF power. For the auxiliary interface, the bit definitions are given in Table 3-VIII. Synchronization proceeds as follows: commander's station waits until the processing load is low (i.e., no R/T status change from its front panel). The commander's station then transmits the status of one R/T to the auxiliary station. The auxiliary station immediately responds with either of the two words from Table 3-VIII. If the command microprocessor does not detect the auxiliary transmission, a time out occurs and the command microprocessor continues to process other information. When the command microprocessor receives a valid transmission from the auxiliary microprocessor, one of two possible actions takes place. The first possibility is to receive word 1 in which case the auxiliary R/T select pointer is updated to point to the information to be sent in the next command to auxiliary station UART transmission. If the change bit is set, then COMSEC is updated for that R/T. The second possibility is receiving word 2 in which case the R/T is updated both in command memory and through UART transmission to the R/T.

Response time for remote tuning is limited by speed of serial interface to the radios. All processing of other information stops during the remote tuning of an R/T. This degrades control response as well as response to PTT. This degradation in control response will only be seen when both command and auxiliary stations simultaneously request an R/T status change. Worst case PTT delay (when radios are not being tuned remotely) is 13.0 ms and is due to the commander-auxiliary interface.

Table 3-VIII. Auxiliary Station UART Bit Definitions

Commander's Station to Auxiliary Station	BITS
Preset	5-7
RF Power	2-4
ECCM	1
CT	0

NOTE: Bits are all zero denotes a remote transmission problem. Bits all one denotes retransmit blank.

Auxiliary Station to Commander's Station	BITS
Word 1 (no remote tuning necessary)	
Not Used	5-7
Update	4
CT	3
R/T Select	1-2
Identifier = 1	0
Word 2 (needs remote tuning)	
Preset	5-7
RF Power	2-4
ECCM	1
Identifier = 0	0

Estimated program size is 900 bytes of ROM. This estimate is high because it was based on using the RCA CDP1802 with no RAM. Only internal registers to the CPU were used for calculations. Since an RCA CDP1804 does have a small amount of RAM on the chip, the program size will be considerably smaller. The 1804 will also make I/O less cumbersome.

Application of Fiber Optic Cable in VIS

The use of fiber optic cable to interconnect the VIS components was considered because of the high ambient noise environment of the track vehicles and the possibility of cable pick-up adding to the system noise and degrading performance. At the present time, there is a lot of activity in optical cable and connector development and although a fiber optic system would have a higher cost than wireline, the cost difference will become smaller in the next three to five years.

ITT-A/OD's VIS would adapt very readily to fiber optic use because of the TDM technique used. The real problem in using fiber optics, other than cost, is the routing of signals through turret ship rings. At the present time there is not enough need to require an optical type of slip ring and it is doubtful if one will ever be developed. This is further substantiated by the fact that the XM-1 tank routes hydraulic lines through the slip ring area which would further complicate implementing an optical slip ring.

In consideration of the wirelines, by utilizing a twisted cable pair and digital techniques, a high degree of noise immunity is achieved and therefore a fiber optic system may not be justified on a cost basis.

Connector Selection

Connectors presently in consideration by ITT-A/OD for the intercom fall into three areas: signal, audio, and binding post.

Signal connectors are the type consistent with MIL-C-26482, Series I. This connector offers high reliability and will withstand the environment the intercom will be exposed to. These miniature circular connectors have a size consistent with the mounting area on the boxes with enough pins to keep the number of connectors at a minimum.

The audio connector is a standard six-pin connector which conforms to the performance requirements of MIL-C-5516. These connectors are mated with a twist-lock motion and have spring-loaded contacts for positive electrical connection with minimum voltage drop.

The binding posts selected are per MIL-P-55149, Type PB08NA01 or an equivalent. These binding posts are designed for use in sealed equipment requiring external connections. Designed for vehicular units, these posts have heavy spring pressure to ensure good contact on small soft wire or heavy steel and copper conductors.

Commander's Station Connector Consideration and Alternatives

The commander's station interfaces with up to ten other boxes (i.e., radio, crew station, etc.). These interfaces represent about 110 wires that could connect to the command station. In addition to the wire numbers, it would be advantageous to leave one side of the commander's station free of connections so installation would take a minimum amount of rework in retrofit situations.

There are four basic approaches to the interconnect wiring:

1. Point-to-point wiring

2. Multi-termination cable

3. Junction boxes in cable

4. Multiplexing to reduce wire numbers.

Point-to-point wiring has a connector for each place the wires are routed. This type of wiring has the following advantages: 1) easy to maintain the wiring system, 2) increased reliability in that if one system fails because of wiring, it has no effect on any other system. The disadvantages are: 1) too many connectors in the commander's box results in operator cable intanglement and potential for wrong connections, and 2) cost increases since internal wiring complexity increases as the number of connectors increases.

Figure 3-16 depicts a typical connector configuration showing locations and sizes of connectors around the commander's control box with this type of wiring.

Multi-termination cable offers the ability to consolidate many little connectors around the commander's box into a few large connectors. The cabling would be constructed in such a manner that it would branch to the various points around the vehicle. This type configuration offers the following advantages:

1. Reduced number of connectors which increases the system reliability.

2. Reduced costs in assembly and in purchased part cost.

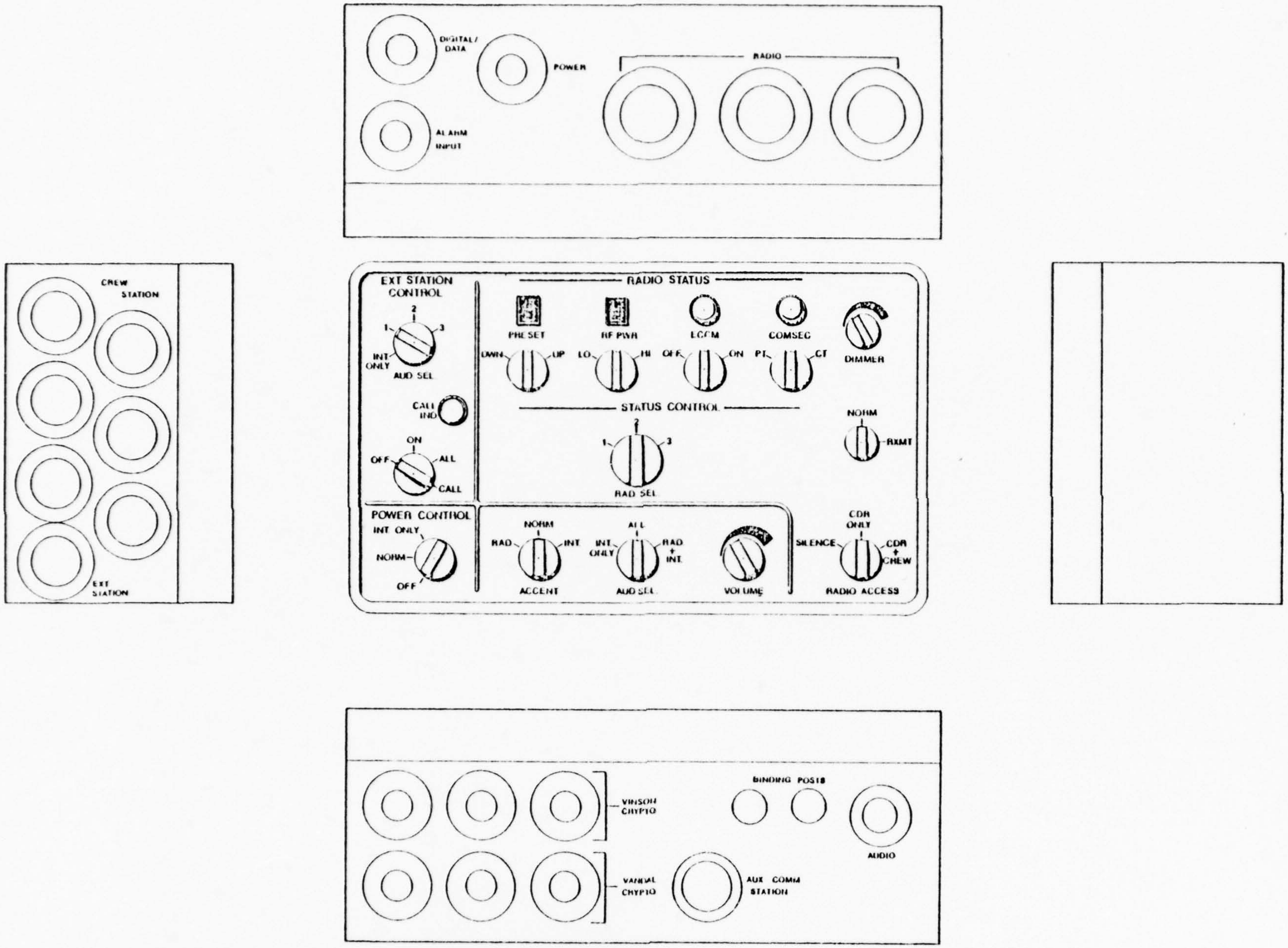


Figure 3-16. Commander's Control Box with Dedicated Connectors

The basic disadvantages are:

1. Maintainability of the branching cable. A great deal of down time would be required to service a cable of this type.

2. Interchangeability of the system components could be a problem if the particular cable in the vehicle did not include provisions for every option.

These problems could be reduced by using protective conduit that would allow wires to pass through it. Connectors and wiring could be maintained without ever removing the complete assembly from the vehicle. This type of system would take up more space than a plain wire cable which is currently used. The cost of the conduit would exceed the savings made by reducing the amount of the connectors. Evaluations of life-cycle cost have not been made.

Junction boxes in the cable offer the following advantages:

1. Consolidated connector at the commander's station to reduce connector clutter and problems in mounting the box.

2. Requires no complicated wiring harnesses.

3. The wiring harness can be maintained in sections that are easy to replace the field.

The disadvantages of such a system would be:

1. Cost in additional connectors.

2. Reliability.

3. Additional space required (for boxes).

Each time one introduces a break in the transmission line, the probability of failure increases.

Figure 3-17 shows a typical connector configuration of the commander's box if multi-termination or junction box wiring were used.

Multiplexing of the circuits would reduce the number of wires by making wires do multi-tasks. This would reduce the number of wires but the problem of how to cable to many unrelated boxes would still exist.

In the final selection of how the intercom system is cabled together, the following criteria must be addressed:

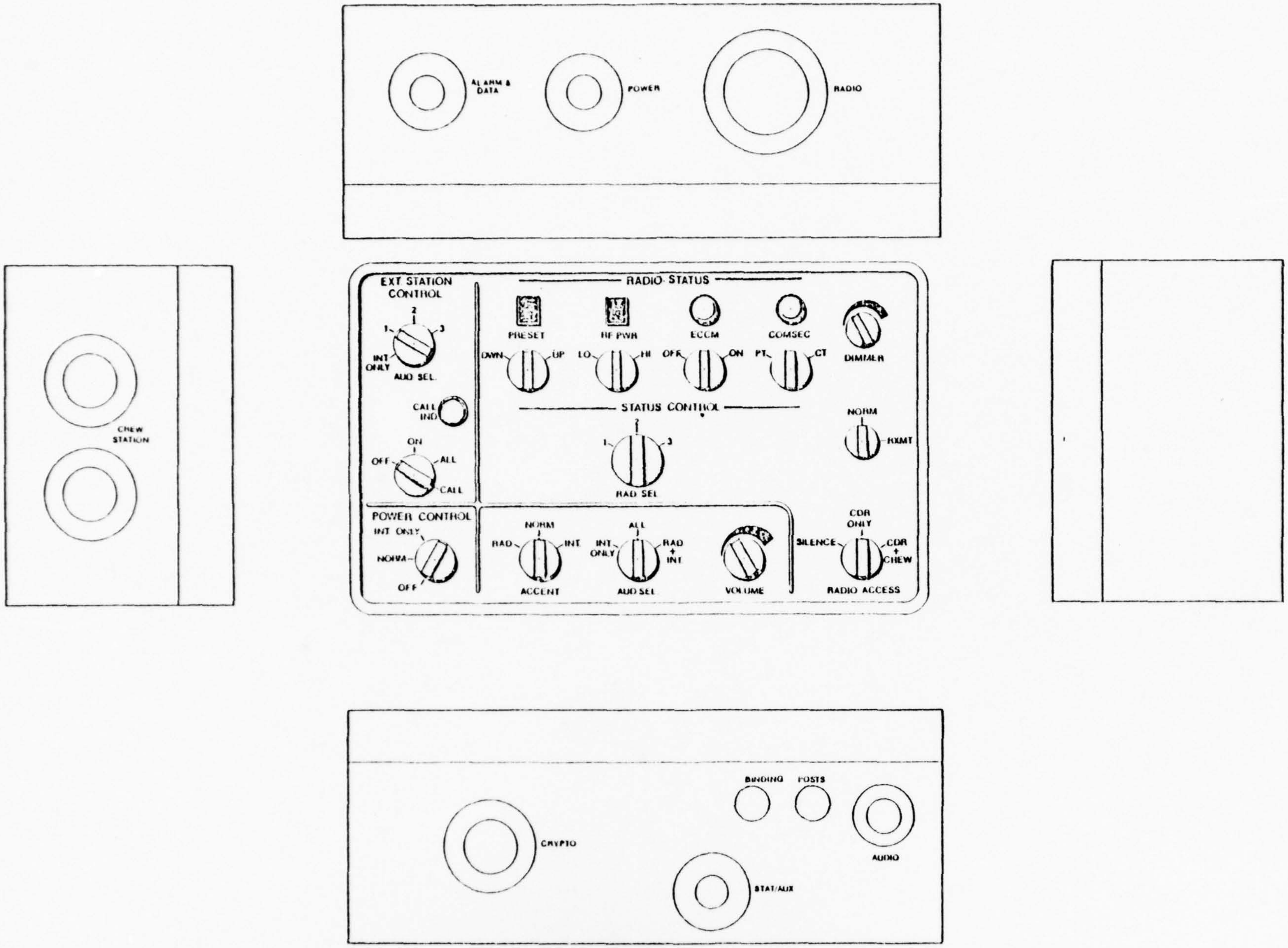


Figure 3-17. Commander's Control Box with Outputs Consolidated to a Few Primary Connectors

1. Maintainability

2. Space conservation

3. Cost

4. Reliability

5. Wiring adaptable to all vehicles

Through trips to various installations and conferences with Government personnel, ITT-A/OD has determined that maintainability is the key issue. To have good maintainability, one must use simple point-to-point cabling. This can be accomplished in a variety of ways (i.e., junction box, in-line cable connectors, etc.).

The final solution will be determined by various trade-offs of the other four criteria for cable selection. This solution will be made at a later time when installation configuration is better defined.

Crew Station Front Panel and Connector Location

Crew station boxes should be approximately the same size as the present system. Probably a slightly reduced size could be expected. Figure 2-3 shows a typical configuration of a crew station. The front panel consists of three knobs: 1) radio select, which controls which radio the crewmember receives or transmits over; 2) audio select, which allows the crewmember to select what he hears; and 3) volume.

The station uses three connectors: 1) links the crew station to the commander's station; 2) an audio connector to connect the crewmember's headset; and 3) a connector which allows the crewmember to use remote keying. Other features which should be considered for the crew station are: 1) quarter-inch diameter shafts for switches and pots; 2) mounting pattern identical to present units; and 3) heavy mounting feet to bolt to.

Location of Commander's Station on M-60 Tank and XM-1 Tank

The ITT-A/OD Intercom System is configured differently from the present AN/VIC-1 system. The "new" intercom system eliminates the AM-1780 and combines all the functions of this module into the commander's station module which is the same physical size as the AM-1780. (A complete description of the ITT-A/OD commander's station can be found in the First Quarterly Report, ECOM-77-0189-1-A).

An auxiliary commander's station, which is the same physical size as the proposed commander's station, will be used by the loader in the tank. In the M-60 it can fit where the present intercom station is; and in the XM-1 it could be located either at the present station location or where the AM-1780 amplifier is located. Figures 3-18 and 3-19 show the typical system hook-up.

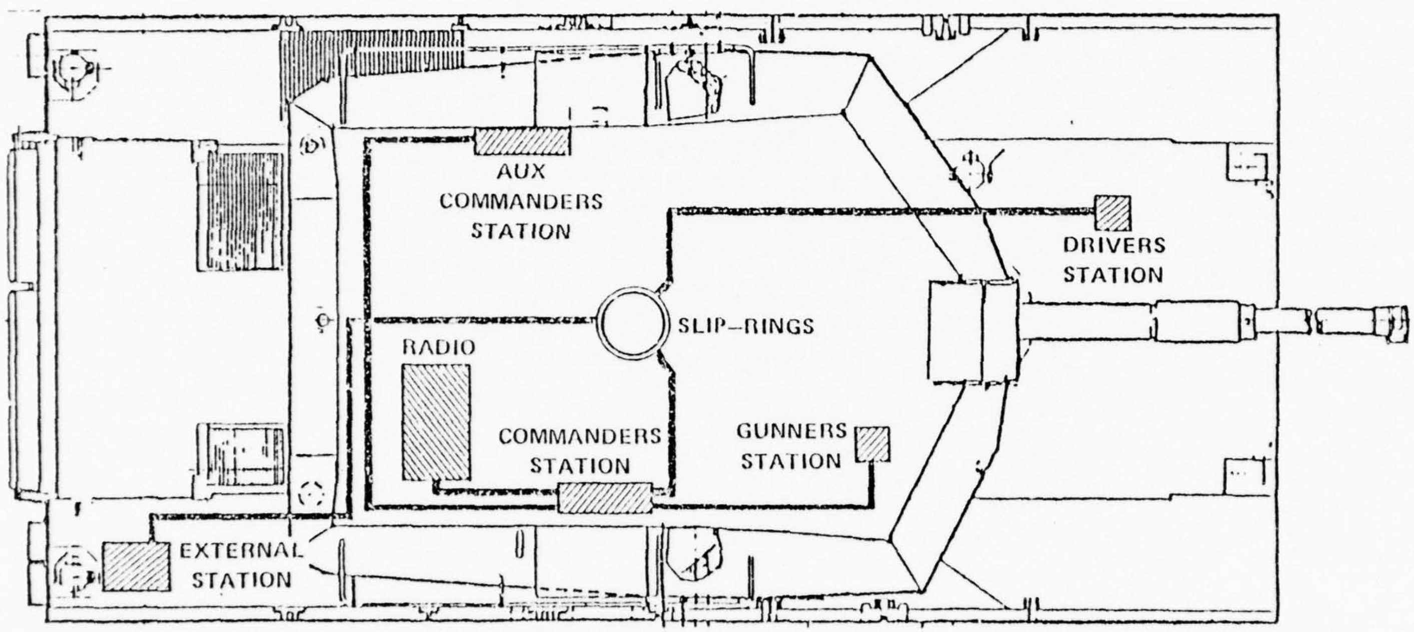


Figure 3-18. M-60 Tank, Typical Intercom Interconnect

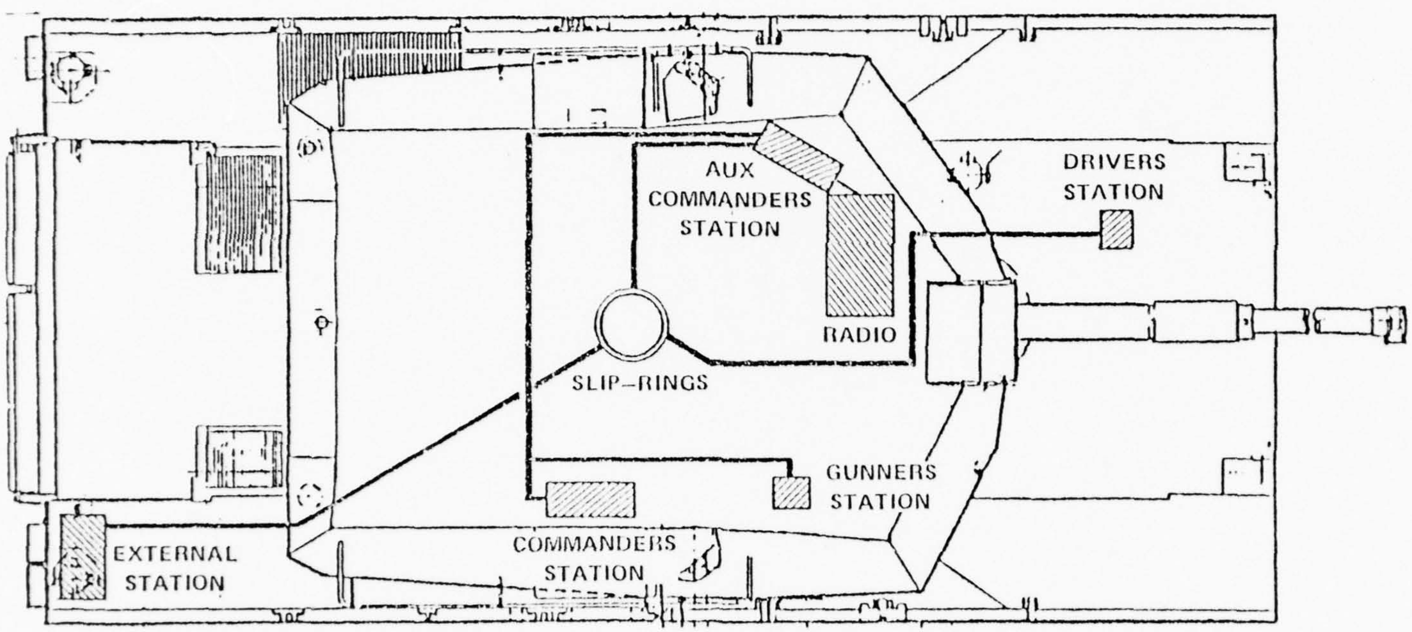


Figure 3-19. XM-1 Tank, Typical Intercom Interconnect

Wireless Evaluation

During the VIS study, wireless techniques were analyzed to determine which could possibly be used in the wireless portion of the intercom. The techniques evaluated were:

- UHF FM 415 MHz
- Microwave
- Ultrasonic
- Infrared

These techniques were evaluated as they would be applied for wireless intercom use with the following being the criteria for selection:

- Operation Suitability - Will the system perform the required functions with little or no additional operator training?
- Difficulty of Implementation - Are there any characteristics of the technique that would not adapt to use in a tracked vehicle, i.e. special mounting requirements, environmental problems?
- Interference Susceptibility - Is there other equipment aboard tracked vehicles which will interfere with a techniques operation?
- EMI or Other Types of Interference - Will this technique interfere with equipment already installed in tracked vehicles?
- TEMPEST - Will information transferred over the wireless link be susceptible to interception by unauthorized people?
- Relative Cost - How does each technique compare as to cost?
- Battery Drain - Because the crew set portion of the wireless intercom must operate on batteries, what is the relative power requirements of each technique?
- Health Hazard - Will any of these techniques be detrimental to the operator's health?

The mathematical analysis for the wireless system is presented in Appendices A and B. A is unclassified and contains the ultrasonic and infrared analysis. B is the classified appendix and contains the microwave and UHF-FM analysis.

The wireless requirement is to provide a wireless intercom for internal use and external use of at least 15 meters and a design goal of 50 meters.

It was discovered in the study for external use the UHF-FM system had the capability for 50 meters. This system however, would not meet the TEMPEST requirements as shown in Appendix B.

A further study was done to select a system which would be required to operate only internally. This resulted in a second technique which was more suited to the tracked vehicle but could not operate reliably external to the vehicle. Table 3-IX compares the techniques when analyzed for both internal and external operation up to 50 meters.

From this portion of the study the UHF-FM system was selected. Because of the on-board interference of the VHF radio equipment the RF power levels required exceed the TEMPEST limits and there is the possibility of the internal RF system interferring with on-board equipment although the recommended RF levels are quite low and if the other equipment meets the susceptibility requirements of MIL-STD-461A, Notice 4, this should not be a problem.

Table 3-X compares the techniques when evaluated for internal use only. Without the outside requirement the infrared is the selected technique of the wireless intercom. This system will not interfere with other on-board equipment, uses inexpensive components and provides a full duplex wireless system. This sytem is susceptible to direct sunlight and will have a high reliability when used external to the vehicle. When operating external to the vehicle there is also a possibility of the infrared being detected with the aid of IR detectors such as night vision goggles.

Table 3-IX. Comparison of Wireless Methods Internal and External, 50m Range

	IR	UHF	Ultrasonic	Microwave
Health Hazard	None	None	Above 10 mW/cm	Above 10 mW/cm
EMI	None	None	None	None
Interference Susceptibility	Washes out in sunlight	Harmonics of VHF Equipment	Engine Noise	None
Relative Cost	Low to medium	Medium to high	Low to medium	High
Battery Drain	1 W for 15 meters	1 W for 50 meters	1 W 20 meters	6 W 50 meters
Difficulty of Implementation	Will not meet 50 meter range, mounting IR devices to vehicle for 360 coverage and assure that devices are protected from trees and brush would be difficult	Simple antenna installation	Similar problem to IR	Implementating a circular patterns with waveguides from a single source would be very difficult & will not transmit 50 meters
Operational Suitability	Capable of full duplex	Half-duplex	Half-duplex	Full Duplex
TEMPEST	No problem	Will not meet TEMPEST requirements	No Problem	Will not meet TEMPEST requirements

Figure 3-X. Comparison of Wireless Methods Inside Vehicle

	IR	UHF	Ultrasonic	Microwave
Health Hazard	None	None	Possibility of power densities higher than 10 mW/cm	Possibilities of power densities higher than 10 mW/cm
EMI	None	Possibility	Possibility	None
Interference Susceptibility	Susceptible to sunlight	Broadband noise from on-board UHF equipment	Engine nose, track noise, and vibration when in motion	None
Relative Cost	Low to medium	Medium to High	Low to medium	High
Battery Drain	1 W	1 W	1 W	2.5 W
Difficulty of Implementation	Lens dirt and clothing covering light path	Simple antenna installation	Difficult to mount so vibration is not impeded, transducer must be vented and is therefore exposed to the environment	Waveguides difficult to implement and circular patterns difficult to achieve
Operational Suitability	System is capable of full duplex operation	If system complies with frequency management rules a narrowband half-duplex system results	Narrowband half-duplex system	Wideband full duplex system
TEMPEST	No known problem	With open hatch	No known problem	No known

4 AVERAGE COST ESTIMATES

Contract DAAB07-77-C-0189, Section F.2, amends specification number DS-AF-0246A(A) Paragraph 3.1.3. It states requirements for an average unit cost estimate for 1,000 systems subdivided in the following manner:

"a. Recurring Manufacturing. Cost of the material, labor and other expenses incurred in the fabrication and check out needed for the final system; including GFE and material as well as costs of subcontractors and purchased equipment.

b. Recurring Engineering. Cost of all engineering effort performed in support of production, including maintainability and reliability engineering, maintenance engineering, value engineering, and production engineering costs associated with the system.

c. Sustaining Tooling. Cost of maintenance, replacement or modification of tools and test equipment after the start of production.

d. Quality Control. Cost of implementation of controls necessary to ensure that a manufacturing process produces a system which meets the prescribed standards."

The system will equip an M-60 or XM-1 tank. It is shown in Figure 4-1 and contains the following components:

- 1 Commander's control station
- 3 Internal crew stations

The study effort of the wireless techniques and external station did not include development of a system to the point that meaningful cost information could be derived. The wireless systems therefore were not included in the costing effort. The estimate was based on schematics, detailed block diagrams, plus breadboarded circuits. Parts lists were derived from all three of these.

The cost estimate assumes a one year LRIP program in 1979 dollars. Resulting estimates are as follows:

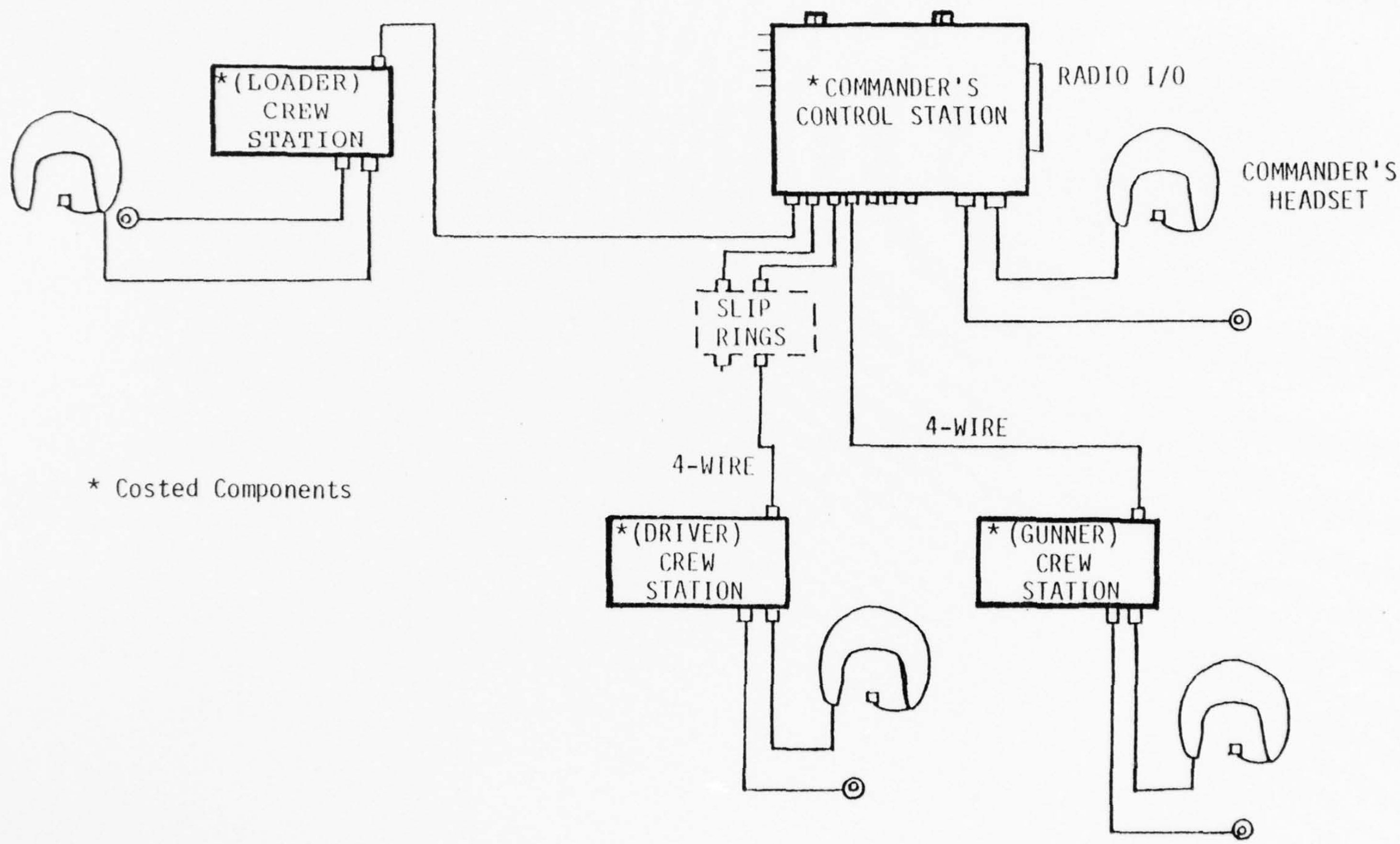


Figure 4-1. System Used for Average Unit Cost Estimate

a. Manufacturing

Commander's Station	$1080		
Three Crew Stations	$ 570	ea.	$1710
			$2790 Sys.

b. Recurring Engineering

Commander's Station	$ 32		
Three Crew Stations	$ 16	ea.	$ 48
			$ 80 Sys.

c. For a level of 1,000 units, sustaining tooling would not be required.

d. Quality Control

Commander's Station	$ 6		
Three Crew Stations	$ 3	ea.	$ 9
			$ 15 Sys.

TOTAL SYSTEM COST

Commander's Station	$1118		
Three Crew Stations	$ 589	ea.	$1767
			$2885 Sys.

The VIS system study incorporated many techniques to reduce the labor requirements to manufacture the system. They include automatic insertion, flexible circuit boards in the place of a wiring harness and connector versus wiring interfaces between printed circuit boards.

Per contract requirement, the estimate covers the anticipated recurring costs for the first one thousand intercom systems in the 1979 time frame. For higher volume production such as ten thousand systems a substantial reduction could be possible. This is particularly true in light of the high CMOS utilization with its current trend toward decreasing costs.

A significant reduction is also substantiated by the history of the AN/VRC-12 radio series equipment, which operates with the present AN/VIC-1 intercom, showed a reduction of one-half to one-third of the initial buy recurring costs after full production volume was reached.

5 LSA RESULTS

Logistics Support Analysis (LSA) Results

LSA responsibility in the study phase was to aid in system configuration which considers:

a. Operation simplicity

b. Maintenance characteristics

c. Provisioning of spares and repair parts

d. Reliability

e. Support and test equipment requirements

and also have the lowest life cycle costs possible. The consideration of a., b., and c. above helped determine the VIS system as it appears in Section 2.0 of this report. Provision d., reliability, is determined of course, by the reliability of the piece parts which are used in the VIS. Determining the "Class" of parts to select becomes a trade-off system cost versus reliability. Using the GEMM computer program to model the VIS it was possible to determine life cycle cost for a given parts "Class" and reliability.

System (same system used for average unit cost estimates Section 4.0) reliability was calculated in accordance with MIL-HDBK-217B.

Using MIL-M-38510, Class B versus Class C parts results in 17,300 versus 2,800 Mean Time Between Failure (MTBF) respectively. The life cycle cost ratio between Class B and Class C parts was 1.44 to 1.0. The cost penalty for a high MTBF must be carefully considered. There is the possibility of combining MIL-M-38510 Class B and Class C parts to have a fairly high MTBF with a lesser increase in life cycle cost. Another option would be to have a burn-in prior to shipping to eliminate infant mortality failures which will increase MTBF and also life cycle cost. These last two options have not been analyzed to provide quantitative data as to MTBF and life cycle cost.

The MTBF for the above analysis was determined by using the formulas specified in MIL-HDBK-217B for calculating CMOS component failure rates. These equations do not take into account reliability increases achieved by operating at lower supply voltages with CMOS parts.

Manufacturers of CMOS devices are constantly trying to improve the reliability of their CMOS devices and their data indicates much lower failure rates than the MIL-HDBK-217B calculations.

There are several manufacturers of CMOS devices which provide high reliability devices. For comparison, Motorola data was used to compare with MIL-HDBK-217B calculations. The results follow:

Reliability Data Source	Device Type	Operating Voltage		Failure Rate	
			55 C	85 C	125 C
Motorola	Composite Avg. of 32 Devices	10 Vdc	.025%/10 Hr	.92%/10 Hr.	28%/10 Hr
		18 Vdc	.6%/10 Hr	15%/10 Hr	.43%/10 Hr
MIL-M- 38510 Class B per MIL-HDBK-217B	4013 Dual-D Flipflop	Not Specified	1.34%/10 Hr	Not Calculated	Not Calculated

From the above data it is seen that a Motorola CMOS part, which is manufactured according to MIL-STD-883, Class C specifications, exhibits significantly lower failure rates if operated at lower than maximum dc.

ITT-A/OD received a MIL-HDBK-217B after the start of the study program. Using Notice 4 provides a 3:1 improvement factor for CMOS stress reduction over the initial calculations which is an improvement but is still below manufacturer's data.

The parts list used and that has been reported on in the first part of this section was developed early in the study program to provide for the first LSAM report. As the study program progressed and the VIS was defined in greater detail, this parts list was expanded and updated to the point that the VIS system could be built with this parts list. The final parts list was used for the "average unit cost estimate" and the LSAM final report. MIL-M-38510, Class C parts were utilized because of the significant reduction of both unit production cost and life cycle costs over MIL-M-38510 Class B parts. The Class C parts do not provide the 12,000 hour MTBF required but does provide a 3,092 hour MTBF and an availability of 97.9 percent which is much higher than 90 percent which is considered adequate.

APPENDIX A

INFRARED WIRELESS COMMUNICATION LINK ANALYSIS

In the proposal two types of infrared (IR) wireless communication were discussed. These were a pulsed FM IR system and a pulse modulated TDM system. In each IR approach, short duration pulses are modulated onto the IR light carrier. In the FM case, the pulses are frequency modulated by the voice signal. In the TDM case, digitized voice plus command signals are pulse modulated onto the light carrier. The following is a general analysis of a pulse modulated IR communication link. The results are applicable to both the FM or TDM pulse modulation formats. For pulse transmission systems, the optimum SNR at the receiver is provided when B (receiver 3 dB BW) is on the order of $0.4/\tau$ where τ is pulse width. For an FM pulse modulated system, a carrier frequency of 100 kHz is typical and the pulse width is between 25 and 50 μs. For a single channel TDM system discussed in Section 3 of this report, the 240 kbps data rate results in a pulse width of about 4 μs. A post detection SNR of at least 10 dB is required for effective FM demodulation and at least 19 dB is required to provide a 10^{-5} bit error rate for the TDM system.

The following analysis will show the performance of an IR link both inside and outside an Army vehicle. It is shown that an IR can easily support the omni-directional transmission of narrow pulses at distances in excess of 3 meters inside the vehicle. The only constraint on such a link is the level of background light interference. For an external IR system, omni-directional transmission at a range of 50 meters is shown to be unfeasible due to the path loss and the interference due to direct sunlight.

A typical single emitter/single detector IR communication link is shown in Figure A-1. Upon analysis of this link a more general IR array configuration for omni-directional communication will be described. In Figure A-1, an LD 271 (GaAs)IR emitting diode transmits TDM pulses and exhibits the following characteristics:

I_F (forward bias current)	= 100 mA
V_F (bias voltage)	= 1.35 volts
Input power = Pin	= 135 mW
Output intensity = I	= 15 mW/ steradian
Efficiency	= 11%
Wavelength	= 0.95 μm
Half intensity beam angle θ_{HI}	= 30°

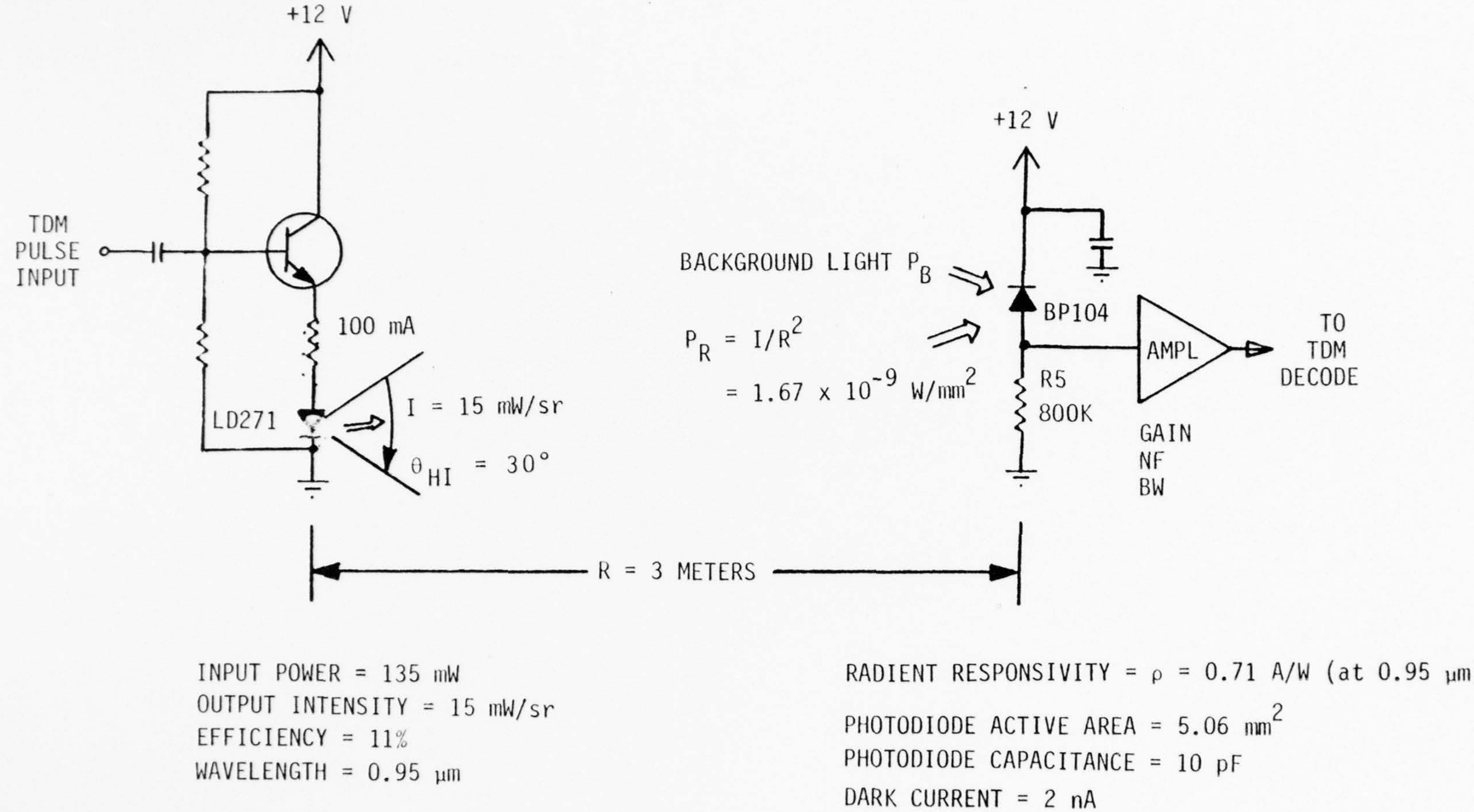


Figure A-1. IR Communications Link

These parameters are further defined in Figure A-1. At the receiver, which is located 3 meters away, a BP 104 photodiode is used to detect the IR TDM pulses. The characteristics of the receiver photodiode are listed as follows:

Radiant Responsivity $= \rho$ = 0.71 μA/μw (@ 0.9 μm)

Photodiode Active Area = 5.06 mm^2

Capacitance = 10 pF

Dark Current = I_d = 2 nA

This communication link can now be analyzed as presented in the following equations. The signal-to-noise ratio at the output of a PIN photodiode receiver is approximated by:

$$S/N = \frac{\rho^2 P_s^2 R_s}{2\,qB\,(P_s + P_b + I_d)\,R_s + 4\,FkT_oB} \qquad (1)$$

where

ρ = responsivity of photodiode (amperes/watt)

P_s = received signal power (watts)

P_b = received background power (watts)

R_s = load resistance (ohms)

q = charge on an electron (1.6×10^{-19} coulomb)

B = bandwidth (Hz)

F = noise factor of preamplifier

k = Boltzmann's constant (1.38×10^{-23} joule/K)

T_o = 290K

I_d = detector dark current (amperes)

An FET preamplifier with an input resistance much greater than R_s is assumed in Equation (1).

The value of the load resistor R_s is determined by the system bandwidth and the photodiode capacitance C_p by:

$$R_s = \frac{1}{2\pi F_c C_p} \qquad (2)$$

where

F_c = cutoff frequency (Hz)

C_p = diode capacity (farads)

For a 40 kbps system and a diode capacity of 10 pF

$$R_s = \frac{1}{2\pi \times 20 \times 10^3 \times 10 \times 10^{-12}} = 800\text{K ohms}$$

A sub-optimum of bandwidth of $B = \frac{1}{2T}$ was used as a first approximation of the required bandwidth. The choice of an optimum bandwidth depends on the amount of inter-symbol interference which can be tolerated.

$$R_S = \frac{1}{2\pi fc}$$

For a 240 kbps system:

$$R_S = \frac{1}{2\pi \times 120 \times 10^3 \times 10 \times 10^{-12}} = 133 \text{ K ohms,}$$

Evaluation of equation 1 for required signal power for the following values:

R_S = 800 K ohms

B = 20×10^3 Hz

ρ = 0.71 A/watt

A/N = 19 dB

I_d = 2×10^{-9} A

F = 3 dB, and

P_d = 0

yields $P_S = 3.55 \times 10^{-7}$ mW for a 40 kbps data system.

Similarly, for

R_S = 133 K ohm

B = 120×10^3 Hz

α = 0.71 A/watt

S/N = 19 dB

I_d = 2×10^{-9} A

F = 3 dB, and

P_d = 0

$P_S = 2.13 \times 10^{-6}$ mW for the 240 kbit/S data system

The required power density, ρ_s is

$$\rho_s = P_s/A_d$$

where

P_S = required input signal power

A_d = active area of photodiode

For R = 3 meters, the required output intensities are 0.63 mW/steradian and 3.79 mW/steradian for the 40 kbps and the 240 kbps systems, respectively. This analysis shows that an IR source such as the LD271 which has an output power of 15 mW/steradian can be used in this application.

Evaluation of Equation 1 for $P_S = 2.13 \times 10^{-6}$ mW and $P_b \to 0$ in the 240 kbps system yields:

$$S/N = \frac{(0.71)^2(2.13x10^{-9})^2 \times 33x10^3}{2 \times 1.6 \times 10^{-19}(0.71x2.13x10^{-6}+0.71P_b+2.10^{-9}) \quad 133x10^3+4\ kT_oBF}$$

$$= \frac{3.04 \times 10^{-13}}{6.44x10^{-20} + 3.02x10^{-14}P_b + 8.15x10^{-23} + 3.84x10^{-15}}$$

Obviously the signal-to-noise ratio is limited by the noise figure of the preamplifier since this term is 5 orders of magnitude larger than the noise due to the signal. By setting the noise term due to background light equal to the noise due to the preamplifier and solving for P_b, the amount of background light required to degrade the signal-to-noise ratio 3 dB is determined.

$$3.02 \times 10^{-14}\ P_b = 3.84 \times 10^{-15}$$

$$P_b = 127\ \text{mW}$$

In an Army tank the level of background light is as yet unknown but is probably in large amount generated by incandescent lights. The use of tungsten filament incandescent lights presents the most severe interference problem, since almost all of the light's output power is generated at IR. For a 10 watt lamp the efficacy (K) of the bulb is 7.9 lumens/watts and the output liminous flux if 79 lumens, the corresponding radiant flux is 10 watts. Most of all radiant power for a tungsten light bulb is dissipated at IR wavelengths at about 1 µm. If a 10 watt tungsten lamp is considered a point source for analysis purposes, then the radiant intensity at 1.0 µm is 790 mW/steradian. The irradiance of a 10 watt bulb at three meters is then 87.7 mW/m^2. The total power which falls on an area of 5.06 mm^2 is therefore 0.444×10^{-3} mW. It may be concluded that an IR wireless system is feasible inside a vehicle unless an inordinate amount of internal illumination is used.

Since an IR wireless approach is possible for internal use, the design of the emitter and detector arrays on the user's set becomes important. It is highly desirable to obtain omni-directional coverage with as few emitters as possible to conserve power for the wireless user. The design of the central transmitter/receiver array at the intercom commander's control station is less critical since power consumption is not a problem. It is proposed that only two LED arrays and two photodiodes be located on each user's headset. Complete angular coverage can be provided by arrays of LED's and photodiodes in the vehicle. This approach offers minimum battery power consumption.

The foregoing analysis is only applicable to IR communications internal to the vehicle where ranges are on the order of 3 meters and interference is due to incandescent lights is not a problem. External to the vehicle the level of background light interference increases, path losses increase at distances of 50 meters and detectability by the enemy becomes a problem. If Equations (1) and (3) are applied to an IR link operating at 50 meters and it is desired to achieve the same signal power required in the previous design case for a range of 3 meters, then the required output intensity of the transmitting diodes is 1 watt/steradian. This high transmit intensity is obviously not practical for the wireless communication system under consideration.

The other limiting factor in utilizing IR wireless techniques external to the vehicle is the presence of sunlight interference. On an overcast day the spectral incidence of sunlight is about $6W/m^2/\mu m$ at a wavelength of 1 μm. The typical bandwidth of an IR receiver in terms of wavelength is about 0.4 μm. The irradiance of the interference reaching the detector is about 2.4 W/m^2. This corresponds to an irradiance of 2.4×10^{-6} W/mm^2. For a BP 104 detector diode with an area of 5.06 mm^2, the detected power level at 1 μm due to sunlight on an overcast day would be about 1.2×10^{-5} W. This level of light interference will not degrade the signal-to-noise ratio at the output of the detector diode. Direct sunlight will definitely render an IR wireless system inoperable.

Conclusion:

The infrared system will adapt readily for internal wireless intercom use. The use external to the vehicle is marginal due to power requirements for the distances involved (15 - 50 meters). Direct sunlight on the photodiodes will wash out the infrared system.

Commercial infrared remote control systems are being developed for television and stereo systems which are bringing the cost of the IR devices down. An IR system can be developed rather inexpensively.

Application considerations will be:

a. The bit rate at which the IR devices are capable of operating

b. How can full 360° operation be achieved by the relatively directive devices?

<u>Operating Rate of IR Devices</u>:

From the analysis and data sheets for IR devices, they are capable of operating at approximately 1 Mbps. As the bit rate is increased, the power requirements also increase. From the viewpoint of the VIS a bit rate high enough to support more than one wireless channel would give the wireless system a higher degree of flexibility. Table A-I gives the bit rate per wireless channel and also the power requirement for operation at 3 meters with a bit error (BER) rate of 10^{-5}.

Table A-I. IR Operating Rate -VS- Power Required for 10^{-5}BER

1 Wireless Channel	240 kbps	3.8 mW/Steradian
2 Wireless Channels	360 kbps	5.7 mW/Steradian
3 Wireless Channels	480 kbps	7.7 mW/Steradian
4 Wireless Channels	600 kbps	9.5 mW/Steradian

When implementing the wireless system, it will be necessary to guarantee operation regardless of the user's position inside the tracked vehicle. If there is no reflection of IR inside the vehicle, satellite IR transceivers would be required around the interior of the vehicle as well as an IR transceiver on the front and the back of the operator as shown in Figure A-2. Each satellite transceiver would contain an IR LED array which will produce a 90° half intensity beam angle. If there are reflections inside the tracked vehicles, then possibly one transceiver could be used with a larger diode array to provide power sufficient for 10^{-5} BER operation.

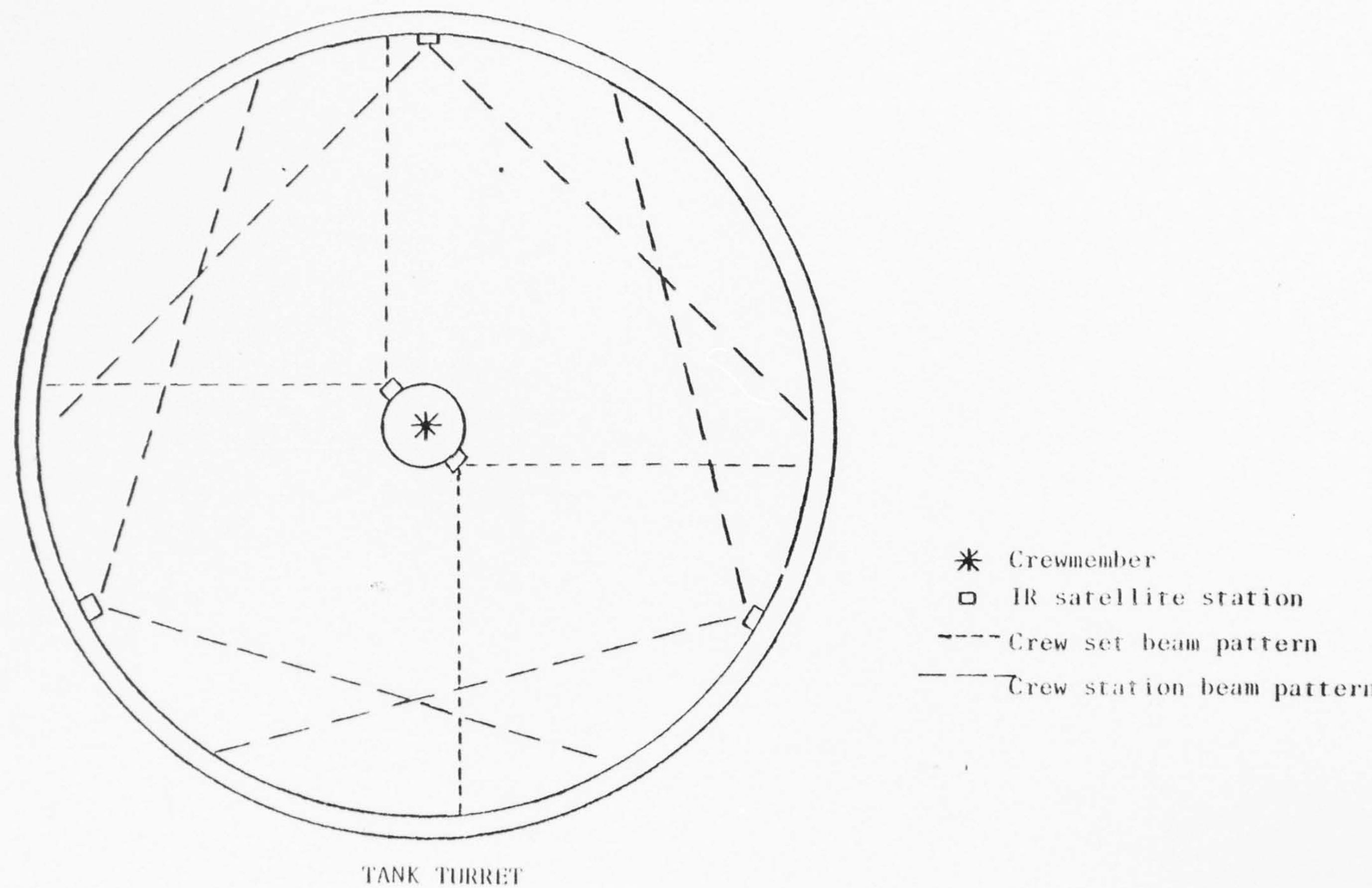


Figure A-2. Radiation Pattern for Emitter Satellites Using Three Satellite Stations on the Tank and Two Satellite Stations on the Crewmember with 90° Half-Intensity Beam Angle

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VEHICULAR INTERCOMMUNICATIONS SYSTEMS.(U)

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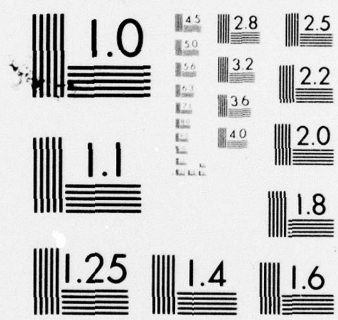

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NATIONAL BUREAU OF STANDARDS-1963-A

ULTRASONIC WIRELESS COMMUNICATION LINK ANALYSIS

Transducers

There are a limited number of transducers that operate in the ultrasonic frequency range. Of these, the piezo electric crystal, are the best choice for the intercom application. The piezo electric transducer has a very high dynamic range of operation. It is relatively rugged and by choosing the proper material is easily driven by solid-state devices. Of the various materials available, the most promising is the barium titanate or lead zirconate titanate. Both of these materials can be driven with relatively low voltage while quartz, which is a good material in many respects, requires a very high voltage drive. Materials such as Rochelle Salt, which has many desirable characteristics, are highly affected by temperature and humidity. The equivalent circuit of a piezo electric transducer is shown in Figure A-3. This circuit represents the normal transmitting circuit; however, the receiver circuit results by replacing the acoustic impedance, R_C, by a generator and connecting the voltage measuring preamplifier at the input terminals. The input impedance characteristic of such a device is shown in Figure A-4.

The minimum impedance is the series resonance point and the maximum impedance is the parallel resonance point. In order to obtain reasonable efficiencies, it is necessary to drive the transducer at its series resonance point and receive on the parallel resonance. One manufacturer states an efficiency of 5 percent is good, but various papers on the subject give efficiencies of 15 percent or higher. In order for a conservative estimate, an efficiency of conversion of electrical to acoustic energy has been assumed to be approximately 10 percent. By having the receiver and transmitter crystal with the same resonant frequencies, a bandpass characteristic can be achieved which appears capable of bandwidths of at least 4 kHz at low frequencies and probably as high as 12 kHz at 100 kHz carrier frequency.

SYSTEMS CONSIDERATIONS

Inside of the armored vehicle, the transducers must cover approximately a sphere although reverberation should allow for some dead spots in the coverage. The background noise inside the armored vehicle is very high. Measurements were taken on a German tank traveling 38 miles per hour over a concrete road. The background noise spectrum is shown in Figure A-5. This is a power density spectrum based on a 6 kHz bandwidth. Data on American vehicles is not available; however, it is assumed that the noise data would

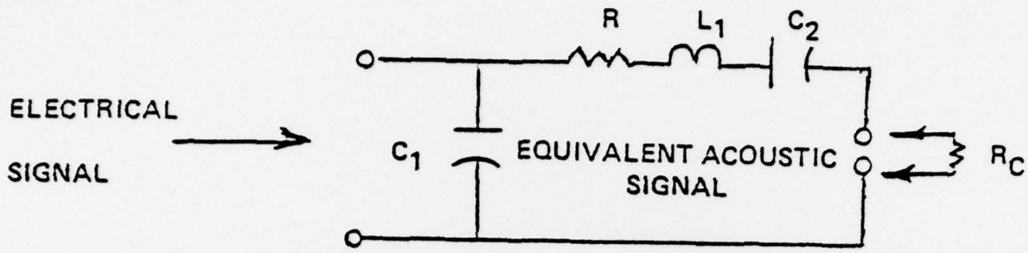

Figure A-3. Equivalent Electrical Circuit for a Piezoelectric Transducer

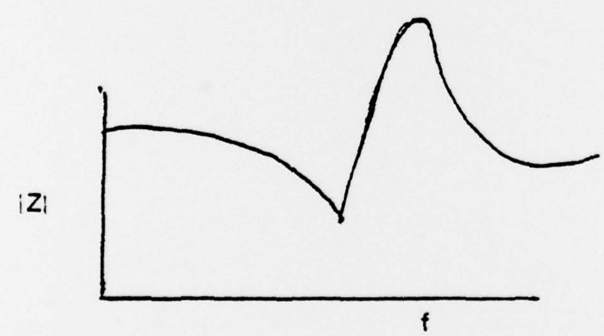

Figure A-4. Typical Input Impedance Characteristics of a Piezoelectric Transducer

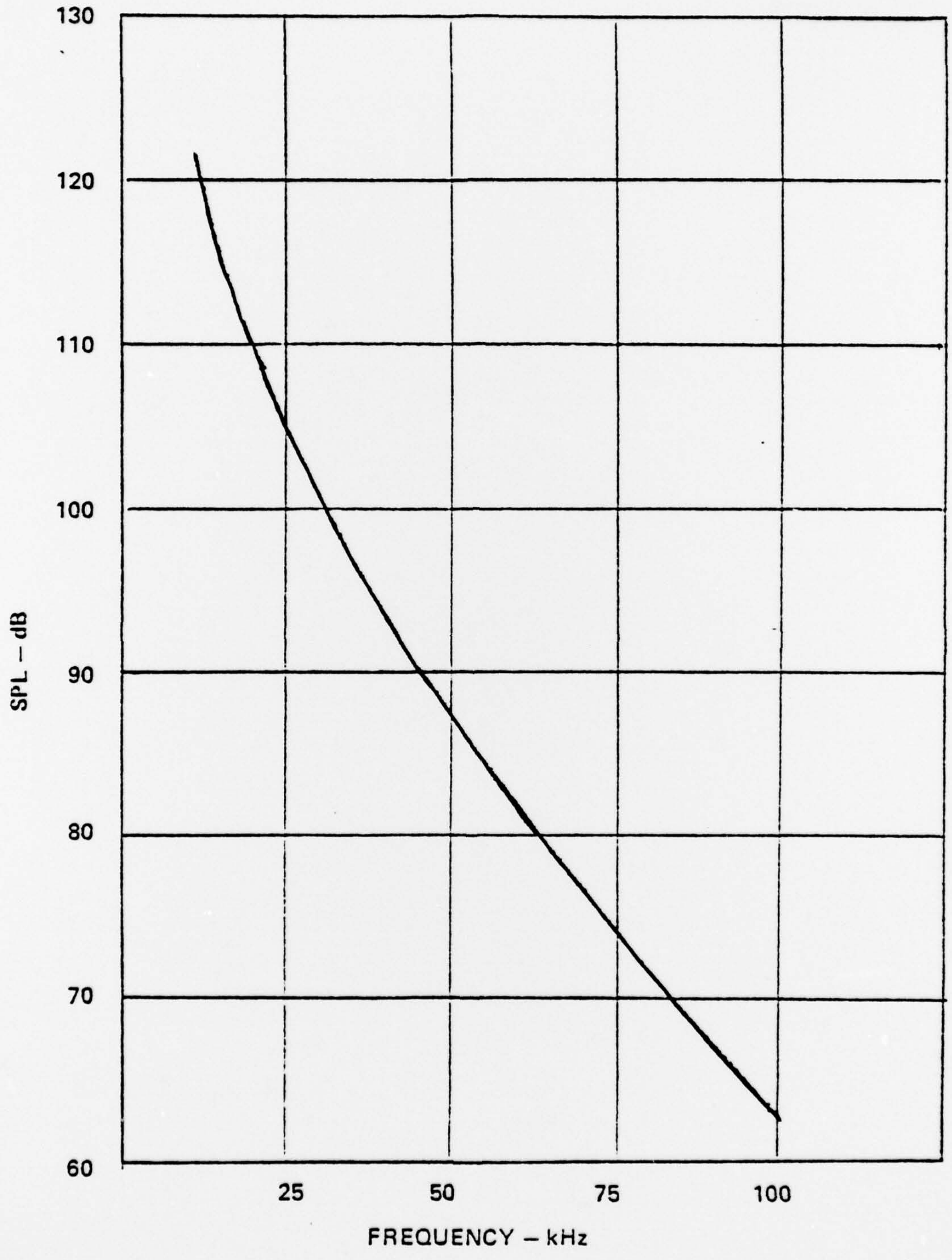

Figure A-5. Measured Sound Pressure Levels -vs- Frequency for a Tank Traveling 38 Miles/Hour on a Concrete Road (Rubber Treads) be similar to that of the German vehicles. With the new generation of tracked vehicles that are faster and lighter, the ambient noise is expected to increase. If a signal noise ratio of 10 dB is assumed and if the transducer is assumed to radiate equally in all directions, and if maximum distance of transmission inside the armored vehicle is five feet, the power frequency curve shown in Figure A-6 results. Power is the acoustic power out. Assuming an efficiency of the transducer of 10 percent means that all of the power values have to be multiplied by 10 for electrical power input. It is assumed that the maximum electrical power is 1 watt. This is for two reasons: possible deleterious effect on personnel and the total power drain. Using an acoustic power of 0.1 watt, a frequency of 60 kHz is obtained from Figure A-6. It is, therefore, proposed that the carrier frequency be 60 kHz and that single sideband operation be used since it is difficult to achieve the widebandwidth necessary to support the sidebands if double sideband is used. With 6 kHz audio bandwidth, a double sideband requires a 12 kHz bandwidth which although feasible with transducers over 100 kHz, is not feasible at 60 kHz. Preliminary study shows that 6 kHz can be achieved with a properly designed transducer at 60 kHz. If carrier suppressed double sideband modulation is used, the transducer characteristic can eliminate the lower sideband.

Multipath problems exist inside the tank. Normally in a reverberation environment, the multipath is so high that the small variations that occur in the spectrum produce little or no distortion. Unfortunately, at frequencies such as 60 kHz, the air attenuation reduces the multipath to the point where significant variations occur in the frequency spectrum. Standard Elektrik Lorenz (SEL) has made measurements that indicated at 70 kHz the distortion of 10 to 20 percent can exist.

A typical air attenuation curve is shown in Figure A-7. It should be pointed out that between 20 kHz and 100 kHz the curve is widely variable depending upon the amount of moisture in the air. The peak attenuation tends to occur at about 20 percent humidity. The curve shown is very close to the peak attenuation. With very dry air, the attenuation is considerably less as shown by the dashed curve.

The propagation outside of the vehicle has the problem that the air attenuation is extreme at the higher frequencies. The attenuation includes not only the geometric attenuation, which is a 6 dB fall-off for every doubling of distance, but also the air attenuation as shown in Figure A-7. Figure A-8 shows attenuation for various frequencies as well as the geometrical attenuation only curve. The required acoustic power versus distance assuming a 40 dB background noise environment is shown in Figure A-9. From this figure,

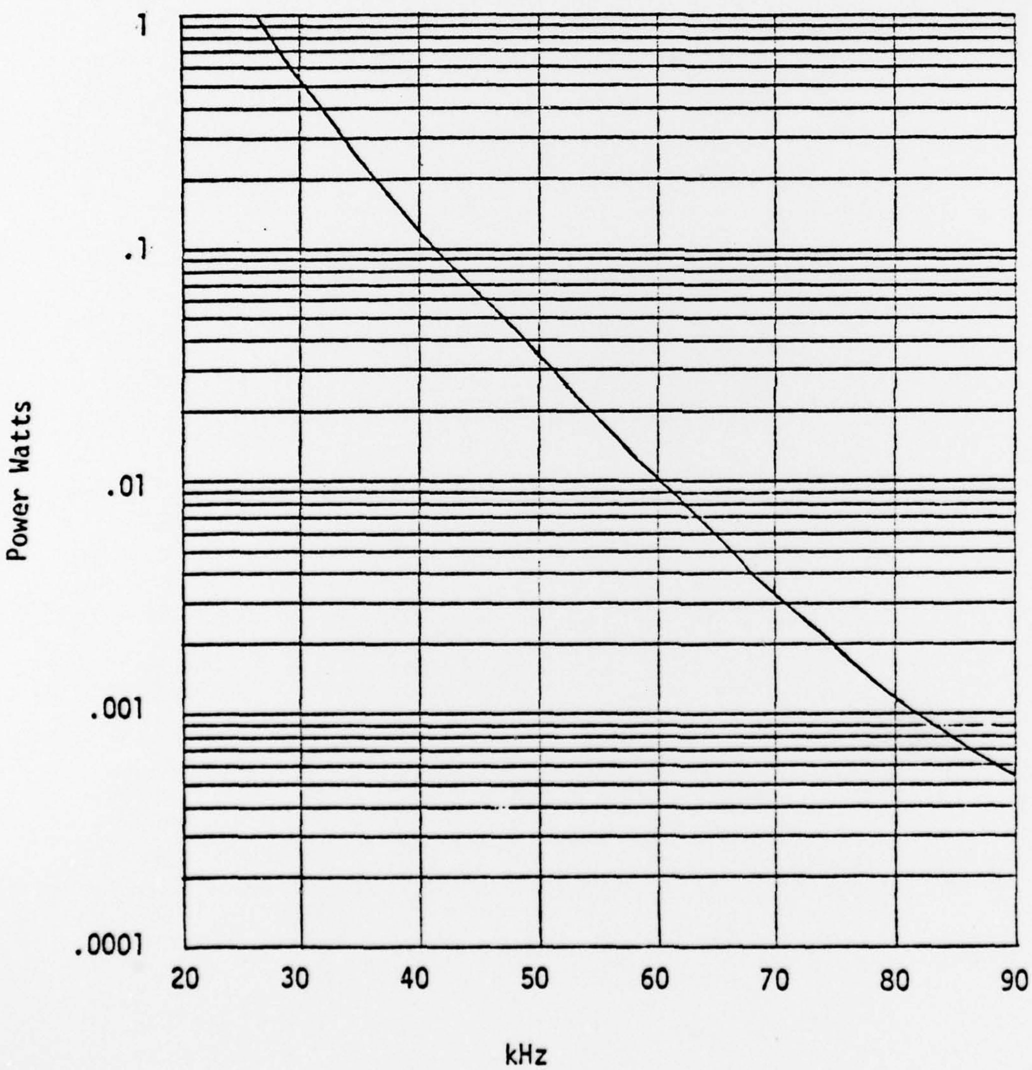

Figure A-6. Acoustic Power for Transmission Inside an Armored Vehicle for a S/N Ratio at the Receiver of 10 dB in a Noise Environment Equivalent to Figure A-5.

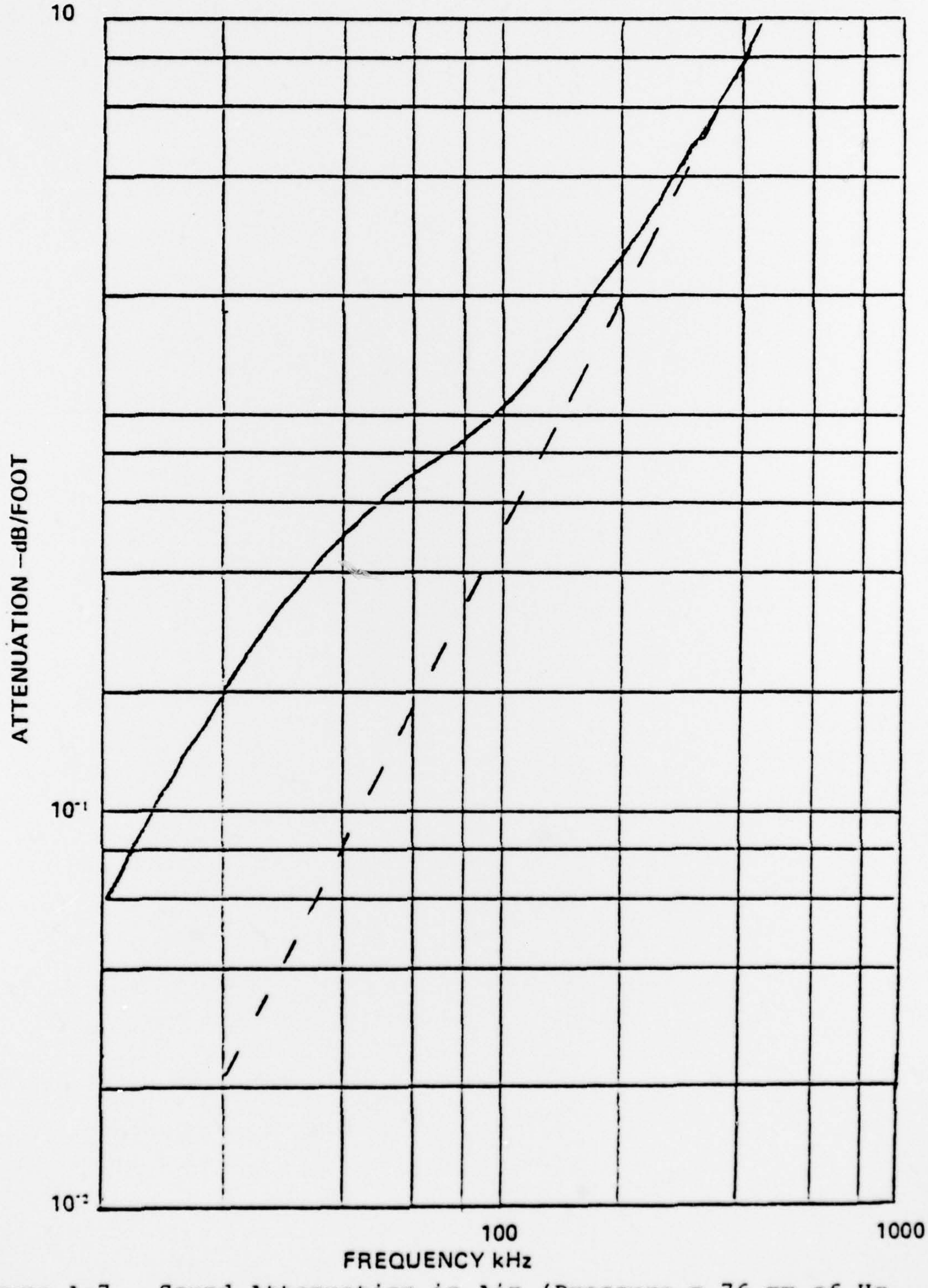

Figure A-7. Sound Attenuation in Air (Pressure = 76 mm of Hg, Temperature = 26.5°, Relative Humidity = 37%). From Sivian, J. Journal Acoust. Soc. Am., Vol. 19, p. 914 (1947).

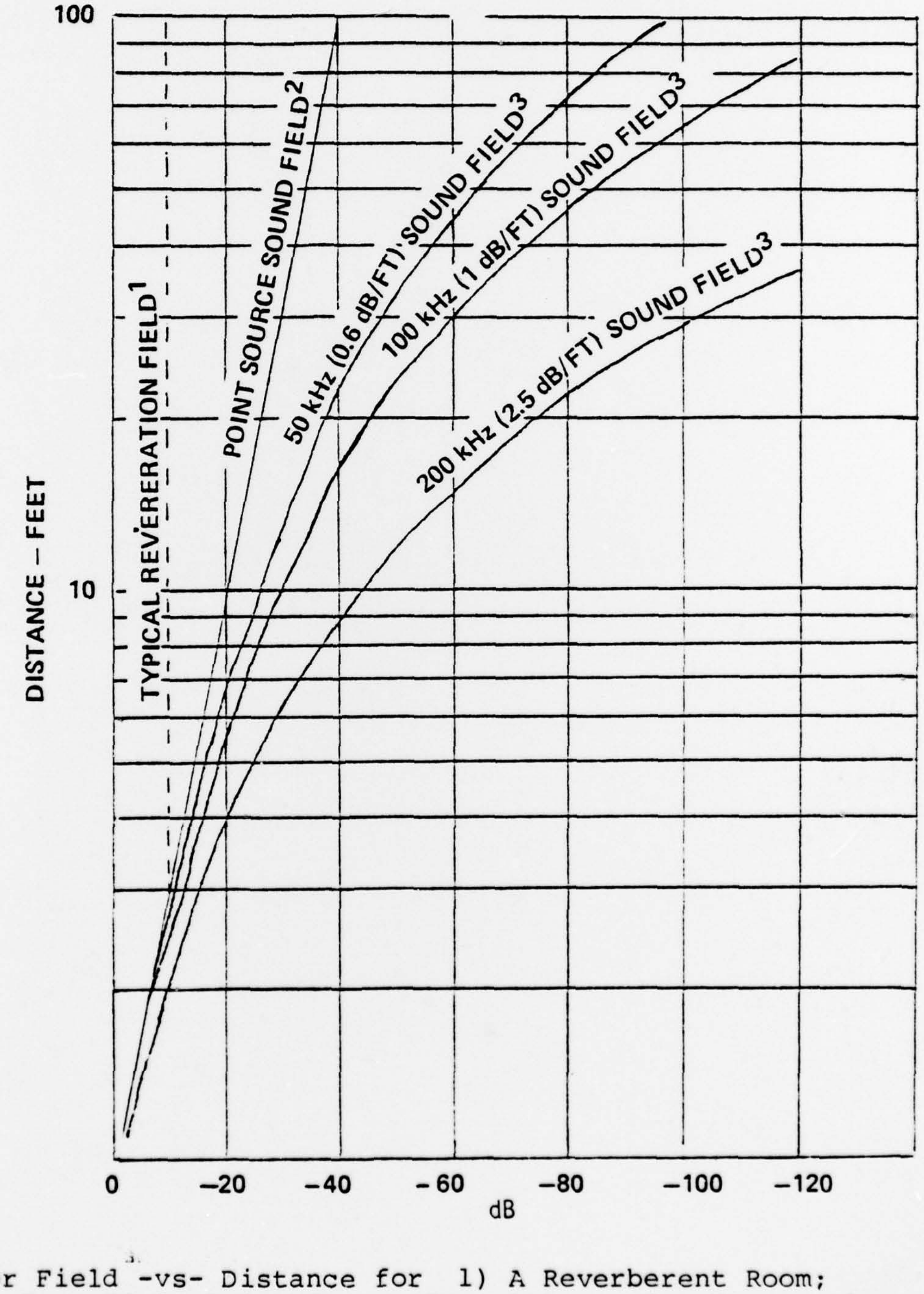

Figure A-8. For Field -vs- Distance for 1) A Reverberent Room; 2) Free Field-Point Source Zero Attenuation Due to the Propagation Medium; and 3) 50, 100, and 200 kHz Free Field

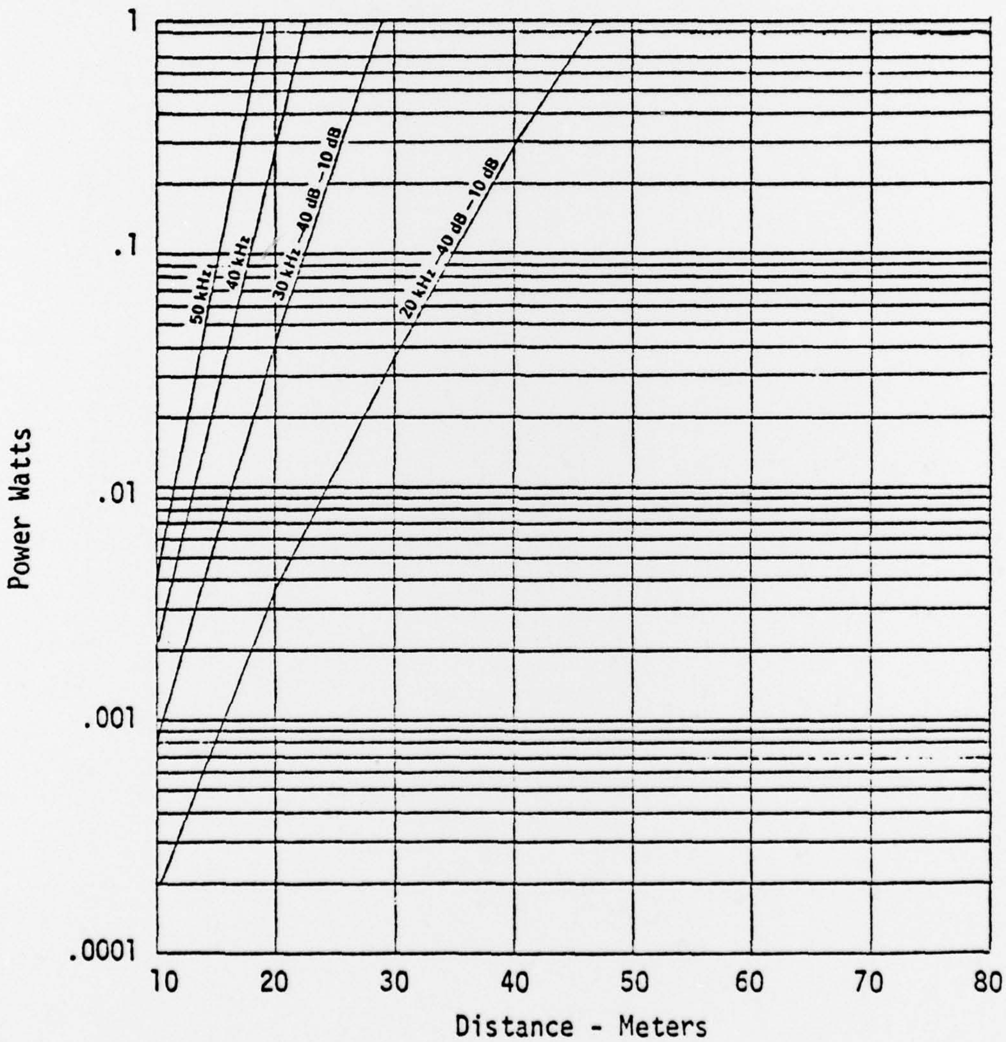

Figure A-9. Acoustic Power -vs- Distance for Several Frequencies Assuming 40 dB Environmental Noise with a Received S/N of 10 dB.

it can be seen that it is virtually impossible to transmit 50 meters with any frequency greater than 20 kHz. If distances on the order of 50 meters are desired, the frequency used for transmission used inside the vehicle cannot be used outside the vehicle. The frequency of 60 kHz gives very little transmission distance outside the vehicle. One item is not known at this time and that is the background noise environment that exists at the ultrasonic frequencies. It is possible that the 40 dB figure is too high. Assuming that it is, the ultimate sensitivity of the receiver becomes a problem. This sensitivity can be calculated based upon the input resistance of the preamplifier connected to the transducer. A figure of about 24 dB of noise is possible under these conditions. This means the curve shown in Figure A-9 can be lowered by a factor of 40:1. The 20 kHz curve shows that it takes 2 watts of power to transmit 50 meters. Since the maximum power that was desired is on the order of 1/10 of a watt, 50 meters would not be achievable; however, if the background environmental noise is not a factor and instead the basic resistor noise is the limitation, then instead of 2 watts, it would only take 0.05 watt and 20 kHz becomes a reasonable frequency to transmit 50 meters.

One of the problems at this low carrier frequency is achieving the necessary bandwidth. The transducers used tend to be high Q and is doubtful that 6 kHz can be achieved at 20 kHz. GTE achieved 3.7 kHz using TV control unit transducers. However, it is questionable that the 6 kHz bandwidth has to be maintained for transmission outside the tank. The individual would not be outside the tank under conditions of high audio noise environment; so that the added bandwidth for intelligibility is probably not necessary.

The other factor is whether the enemy can pick up the acoustic transmissions. One of the advantages of ultrasonic transmission outside the vehicle is that of the attenuation due to the air on a per unit distance basis. For example, at 20 kHz the attenuation per foot is 0.2 dB (dry air = 0.020 dB/ft). This means that at 300 meters, the signal would be further attenuated 164 dB (16.4 dB in dry air) due to the air plus another 15.6 dB due to the geometrical attenuation for a total of 179.6 dB (32 dB). Assuming that the enemy has the same sensitivity receiver, he must have approximately 9×10^{17} (1600) times the area of transducer that is located on our receiver (a parabolic reflector). This is possible in dry air only, but doubtful. If one is willing to accept somewhat shorter distances, the air attenuation can make the transmissions extremely secure. For example, at 30 kHz it is possible to transmit probably slightly in excess of 35 meters, assuming that the background noise is less than 20 dB. Attenuation per foot at 30 kHz is 0.35 dB (0.045 dB in dry air) as compared to 0.2 dB for 20 kHz.

Further, the transmission is less so that at 300 meters, there would be approximately 50 dB of excess attenuation in dry air or a ratio of areas of 10^5:1. It appears that the transmission outside the vehicle will have to be at a frequency somewhere between 20 and 30 kHz if anywhere close to the 50 meters is achieved.

It is envisioned that the system would consist of two separate systems; one for inside the armored vehicle and one for outside. Inside, the transducers would be mounted on the helmet. With a 60^o beamwidth, it would take six transducers arranged around the periphery of the helmet to give the proper coverage. These transducers would take approximately 1 watt of electrical power in the transmission mode. The same transducers could be used for the receiving function if the switching can be achieved. A carrier frequency of 60 kHz would be used. The bandwidth would be achieved by the combined receiver/transmitter characteristics. The signal would be double sideband carrier suppressed modulation with the lower sideband eliminated by the attenuation characteristics of the transmitter and receiver. The transmitting and receiving elements of the station located on the vehicle periphery would have to be arranged equally around the periphery of the armored vehicle. Six would be sufficient to achieve the coverage necessary. For operation outside the vehicle, the transducer used would be of the flextural mode type and it is doubtful whether these transducers could withstand normal battle conditions. Therefore, they would have to be on a unit that would be located outside the vehicle when it is desired to transmit outside. In order to achieve a reasonable distance of transmission from the vehicle, a carrier frequency on the order of 20-30 kHz would have to be used with a bandwidth probably under 6 kHz but at least in excess of 3 kHz. The same method of transmission and modulation would be used as is used inside except with a different carrier frequency. This would require separate transducers and it means the individuals going outside the tank would have to change transducers for this purpose. The only way around this problem is to use directional type transmission which would require the individual to point toward the tank. It is assumed sufficient power could be generated within the tank to provide sufficient transmitting power in a 360^o azimuth. Depending upon the degree of security of transmission desired would tend to determine whether the frequency is closer to 20 kHz or closer to 30 kHz. Overall, the ultrasonic method provides the greatest security to interception by the enemy.